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Manhattan District History

Book VI – Liquid Thermal Diffusion (S-50) Project

MANHATTAN DISTRICT
HISTORY Book VI
S-50 PROJECT

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BOOK VI - LIQUID THERMAL DIFFUSION (S-50) PROJECT

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FOREWORD

This history has been prepared to serve as a source of historical information on the S-50 Project for War Department officials, and ultimately for other authorized individuals. It presents the history of all significant features of the research, development, engineering, design, construction, and operations connected with the S-50 Project. The book was originally prepared to cover a period of time extending generally from 26 June 1944, the date of inception of the S-50 Project, to 1 June 1946, approximately nine months after the termination of S-50 operations. Since there have been no new developments during the latter half of 1946, the period covered may be extended through 31 December 1946, at which time administrative responsibility passed to the United States Atomic Energy Commission.

In Section 2, for the sake of completeness, the scope is somewhat broadened to outline briefly the history of thermal diffusion research, from an early observation of the phenomenon in 1856, to the investigations in progress at present.

Material necessary for a clear understanding of the narrative is presented in the appendices: maps, charts, drawings, graphs, photographs, tabulations, documents, a glossary, a bibliography, and a list of material in the Manhattan District files to which reference is necessary on various subjects. A Top Secret Supplement is also provided, in a separate binder, containing production data. In the text the appendices are referred to by letter and the item by number, except in the case of Appendix "H", the glossary, which is indicated by an asterisk (*). Each

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appendix is preceded by a list of items contained therein.

Since the history of the S-50 Project is closely interwoven with the histories of the Gaseous Diffusion (K-25) Project and the Electromagnetic (Y-12) Project, numerous references are made to Book II and V which cover those projects in the Manhattan District History.

The text is preceded by a summary which is a condensation of the text itself and is provided so that the reader may get a condensed but comprehensive picture of the subject matter, if desired, without reading the entire volume. The summary is keyed to the text by using the section titles of the text as paragraph headings in the summary.

21 May 1947

MANHATTAN DISTRICT HISTORY

BOOK VI - LIQUID THERMAL DIFFUSION (S-50) PROJECT

TABLE OF CONTENTS

Par. No.		Page No.
	FOREWORD	
	SUMMARY	
	SECTION 1 - INTRODUCTION	
1-1	Purpose	1.1
1-2	Scope	1.1
1-3	Authorization	1.1
1-4	Selection of Process	1.2
1-5	Summary of Costs	1.2
	SECTION 2 - RESEARCH AND DEVELOPMENT	
2-1	Basic Theory	2.1
2-2	Development of Theory	2.2
	a. Theoretical Discovery of Phenomenon	2.2
	b. Experimental Confirmation	2.2
	c. Invention of the Thermal Diffusion Column	2.2
	d. Thermal Diffusion in Liquid Solutions	2.3
	e. Separation of Isotopes	2.3
2-3	Development of Operating Process	2.4
	a. Preliminary Development	2.4
	b. Selection of Working Substance	2.5
	c. High-Temperature Experiments	2.6
	d. Determination of Optimum Dimensions	2.7
	e. Pilot-Plant Research	2.8
	f. Production Plant Development	2.10
	g. Further Process Studies	2.10
2-4	Description of Process	2.11
	a. Process Material	2.12
	b. Material Feed and Withdrawal	2.13
	c. Process Steam	2.14
	d. Cooling Water	2.14
	SECTION 3 - DESIGN AND CONSTRUCTION	
3-1	Introduction	3.1
	a. Selection of Original Construction Contractor	3.1
	(1) Original H. K. Ferguson Company Contract	3.1
	(2) Subcontracts	3.2

GROUP-1
Excluded from automatic
downgrading and

Par. No.		Page No.
	b. Selection of New Boiler Plant Construction Contractors	3.2
	(1) Second H. K. Ferguson Company Contract	3.3
	(2) J. A. Jones Construction Company, Inc., Contract	3.3
	(3) Minor Contracts	3.3
3-2	Naval Research Laboratory Design	3.4
3-3	Site Selection	3.5
	a. Reasons for Selection	3.5
	b. Location	3.5
	c. Objections Registered	3.5
3-4	H. K. Ferguson Company Design	3.6
3-5	Process Equipment Design	3.6
	a. Problems in Column Manufacture	3.6
	b. Material Feed and Withdrawal Equipment	3.8
3-6	Process Steam System	3.9
	a. Introduction	3.9
	b. Steam Supply from the K-25 Power House	3.10
	(1) Desuperheating and Pressure Reduction	3.10
	(2) Delivery and Condensate System	3.11
	(3) Auxiliary Facilities	3.11
	c. Steam System of New S-50 Boiler Plant	3.12
	(1) Change in Steam Specifications	3.12
	(2) Boiler System	3.12
	(3) Tank Farm	3.13
3-7	Cooling Water System	3.14
3-8	Construction Schedules	3.15
	a. Main Process Plant	3.15
	b. New Boiler Plant	3.16
3-9	Procurement	3.17
	a. Main Process Plant	3.17
	b. New Boiler Plant	3.17
3-10	Construction Chronology	3.18
	a. Main Process Plant and Auxiliary Buildings	3.18
	b. New Boiler Plant	3.19
3-11	Labor Procurement	3.20
3-12	Security	3.21
3-13	Safety	3.21
3-14	Summary of Design and Construction Costs	3.22
	SECTION 4 - DESCRIPTION OF PLANT	
4-1	Buildings	4.1
4-2	Process Equipment	4.2
	a. Column	4.2
	b. Rack Equipment	4.2
	c. Reservoir	4.4
	d. Convection Loop	4.4
	e. Control Room Equipment	4.5

Par. No.		Page No.
	f. Milker	4.5
	g. Assay Laboratories Equipment	4.6
4-3	1000 p.s.i. Process Steam Equipment	4.6
	a. Desuperheating Water Pumps	4.6
	b. Venturi Type Desuperheating Elements	4.6
	c. Throttling Valves	4.6
	d. High-Pressure Piping	4.6
4-4	New Boiler Plant	4.7
	a. Boiler House Equipment	4.7
	(1) Boilers	4.7
	(2) Boiler Feed Pumps	4.7
	(3) Make-up Pumps	4.7
	(4) Forced Draft Fans	4.7
	(5) Condensers	4.8
	(6) Fuel System	4.8
	(7) Condensate System	4.8
	(8) Miscellaneous	4.8
	(9) Piping	4.9
	(10) Boiler Control System	4.9
	b. Tank Farm Equipment	4.9
	(1) Oil Storage Tanks	4.9
	(2) Pumping Equipment	4.9
	(3) Boiler Plant No. 2	4.10
	(4) Miscellaneous Equipment	4.10
4-5	Cooling Water Equipment	4.10
	a. Cooling Water Pumps	4.10
	b. Make-up Water Pumps	4.10
4-6	Water Treatment Plant	4.10
4-7	Utilities	4.11
	a. Water Supply	4.11
	b. Sewage Disposal	4.11
	c. Steam Heat	4.11
	d. Electrical Supply	4.11
	e. Rail Transportation	4.13
	f. Water Transportation	4.13

SECTION 5 - OPERATIONS

5-1	Selection of Operations Contractor	5.1
5-2	The Fercleve Corporation Contract	5.1
5-3	Specifications of Final Product	5.2
5-4	History of Operations	5.2
	a. Personnel Training at Philadelphia Pilot Plant	5.3
	b. Pilot Plant Explosion	5.3
	c. Preliminary Operations	5.3
	d. Initial Production	5.4
	e. Large-scale Production	5.4
	f. Production Record	5.4

Par. No.		Page No.
5-5	Method of Operation	
	a. Rack Procedures	5.4
	(1) Freeze-off Technique	5.5
	(2) Elimination of Plugs	5.5
	(3) Prevention of Intercolumn Mixing	5.6
	(4) Prevention of Pitching	5.7
	(5) Product Withdrawal Procedures	5.8
	b. Handling of Process Material	5.9
	(1) Raw Material	5.11
	(2) Salvage Material	5.11
	(3) Losses of Material	5.12
	(4) Depleted Material	5.13
	(5) Product	5.13
	c. Control	5.14
	(1) Product Control	5.15
	(2) Process Control	5.15
	(3) Assay Laboratories	5.16
	d. Conditioning of Equipment	5.16
	(1) Reservoirs	5.17
	(2) Columns	5.17
	(3) Auxiliary Parts	5.18
	e. Supply of Utilities	5.18
5-6	Factors Hampering Operations	5.19
	a. Steam Difficulties	5.19
	(1) Lack of Steam	5.19
	(2) High-Pressure Steam Leaks	5.19
	(3) Design Changes	5.19
	b. Lack of Pilot Plant Experience	5.20
	c. Lack of Trained Operating Personnel	5.20
5-7	Industrial Relations	5.20
	a. Labor Procurement	5.21
	b. Wages and Hours	5.21
	c. Schooling	5.22
	d. Safety and First Aid	5.22
	e. Housing	5.22
	f. Transportation	5.24
	g. Working Conditions	5.25
5-8	Security	5.25
5-9	Shutdown	5.25
	a. Termination of Operations	5.26
	b. Termination of Employees	5.26
	c. Disposal of Buildings and Equipment	5.27
	d. Disposal of Records	5.28
5-10	Summary of Operating Costs	5.28
		5.28
	SECTION 6 - ORGANIZATION AND PERSONNEL	
6-1	Introduction	
6-2	Naval Personnel	6.1
		6.1

Par. No.		Page No.
	a. Naval Research Laboratory Organization	6.1
	b. Naval Personnel Concerned with S-50 Project	6.1
6-3	Manhattan District Personnel	6.2
	a. Officer Personnel	6.2
	(1) Contracting Officer	6.2
	(2) Unit Chief	6.2
	b. Enlisted Personnel	6.2
6-4	Major Construction Contractors	6.3
6-5	The Ferguson Corporation	6.3

APPENDIX "A" - MAPS, CHARTS, DRAWINGS, AND GRAPHS

APPENDIX "B" - PHOTOGRAPHS

APPENDIX "C" - LIST OF CONTRACTORS

APPENDIX "D" - DOCUMENTS

APPENDIX "E" - TABULATIONS

APPENDIX "F" - BIBLIOGRAPHY OF SCIENTIFIC PUBLICATIONS

APPENDIX "G" - FILE REFERENCES

APPENDIX "H" - GLOSSARY OF TECHNICAL TERMS

INDEX

SUMMARY

1. Introduction. - The primary purpose of the S-50 Project was to supply feed with above-normal concentration of Uranium-235 to the Electromagnetic (Y-12) Project until such time as the Gaseous Diffusion (K-25) Project could get into production. Authorization was derived from the First War Powers Act of 1941, and expenses incurred in construction and operation were charged to specified procurement authorities. The project was concerned with increasing the concentration of Uranium-235 from the naturally occurring 0.71 per cent to 0.85 per cent; a peak production was reached in the month of June 1945. Progress by the Naval Research Laboratory in developing the liquid thermal diffusion process was followed by the Office of Scientific Research and Development, and the process was selected in June 1944 when its advantages became apparent. Research cost was borne by the Navy, and Manhattan District costs included $12,910,639 for design and construction, and $6,992,616 for operation, making a total of $19,903,255.

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2. Research and Development. - The basic theory of liquid thermal diffusion involves a combination of two factors: the factor of thermal diffusion, which, in many fluid mixtures, causes higher concentration of one component near the hotter of two surfaces, and the factor of convection, which carries the lighter material near the hot wall upward, thus developing a vertical concentration gradient. Thermal diffusion apparatus, called a "column", consists of a long, vertical, externally cooled tube, with a hot concentric cylinder on the inside. Enskog in

1911, and Chapman in 1916, independently made the theoretical discovery that a temperature gradient impressed across a gaseous mixture produces a differential diffusion independent of other influences. In 1917 Chapman and Dootson confirmed these calculations by experiment. Clusius and Dickel in 1938 invented the first column by running a hot wire along the central axis of a long vertical tube. The apparatus was later modified by Bramley and Brewer who used two concentric tubes at different temperatures.

Successful separation of the isotopes of hydrogen and zinc by contemporary workers led to the investigation by P. H. Abelson in July 1940 of the possibility of separating uranium isotopes by thermal diffusion. The discovery of uranium fission had aroused the interest of the Navy in Uranium-235 as a source of power, and the Naval Research Laboratory in September 1940 contracted with the Carnegie Institution to have Abelson expand the experiments. In October 1940 the work was moved to the National Bureau of Standards, where eleven liquid thermal diffusion columns were constructed. The diameter of the annular spaces of these columns was approximately $1\frac{1}{2}$ inches, and they ranged in length from two to twelve feet. They were made up of an inner steam heated pipe, and an outer concentric pipe cooled by water flowing through an encasing jacket. Tests were run on water solutions of potassium salts, and relaxation time and separation factor were found to depend critically on wall spacing and temperature gradient. The sole uranium-containing working substance which showed promise of being practical was uranium hexafluoride, UF_6. Abelson devised a method for large scale production of this substance which involved drying of uranium tetra-

fluoride prepared by the wet chemical method, and fluorinating at 350°C. Physical properties of this substance were then studied, analytical techniques were developed, and runs were made which yielded positive isotope separation although doubts arose as to the accuracy of the assay of the product.

On 1 June 1941 Abelson entered the employ of the Naval Research Laboratory. A number of 36-foot columns were built with varying spacings for use in high temperature experiments at the Anacostia Naval Station. Positive results were obtained with the first one in the separation of chlorine isotopes, but the column was ruined by decomposition of the carbon tetrachloride working substance. The next run, on a new column, showed $2\frac{1}{2}$ percent separation. Further studies led to a separation factor of 21 percent, and the optimum wall spacing was bracketed between 0.21 and 0.38 mm. At this point it was decided that experimentation with one column at a time would take too much time, and also that it was desirable to experiment with the operation of banks of columns connected together in various ways. A pilot plant installation was therefore built at the Anacostia Naval Station. Operation was begun on 15 November 1941, and subsequent experience showed that the unit was capable of remarkably smooth and trouble-free operation. Studies were continued, but it was felt that, in order to reduce equilibrium time, and increase production, a greater temperature gradient was needed. Accordingly, the Naval Research Laboratory constructed a high pressure steam pilot plant at the Philadelphia Navy Yard. By June 1944, this unit was nearly complete; and operating technique had been planned to an advanced degree. By sending trained personnel to the S-50 site, the NRL transferred its

knowledge to the Project.

During the operation of the S-50 plant, extensive process improvement studies were carried on by the operating contractor, the Fercleve Corporation. Operation of the Philadelphia Pilot Plant was also continued during this period and for some time subsequent to the shutdown of the S-50 plant. Since a pilot plant of this size is no longer required, it has been shut down; and work is now continuing in the Naval Research Laboratory at Washington, D. C. The principle present objective is to achieve a more perfectly fabricated column.

In the process developed, the S-50 plant obtained an enriched product containing about 0.85 percent Uranium-235 as opposed to the naturally occurring 0.71 percent. Concentration of waste was 0.67 percent. The working substance, uranium hexafluoride, is a white crystalline solid under atmospheric conditions with a tendency to sublime. Its critical temperature is 450°F; and under the operating pressure of 1500 p.s.i., the substance melts at 155°F, while undergoing a 35 percent expansion in volume which was an important factor in the design of equipment and determination of operating procedures. All points in the process system were maintained above 155°F in order to keep the material in a fluid state so that it could be circulated through tubes and pipes. Although the temperature of the hot wall was above the critical temperature of UF_6, there was no discontinuous interface or sudden change of phase within the annular spaces of the columns. Since the operating pressure was well above the critical pressure, a gradual, continuous transition existed between the walls in which the properties of the material passed from those characteristic of a gas

near the hot wall to those characteristic of a liquid near the cold wall. The extremely corrosive nature of the UF_6 made it necessary to use pure nickel for all process lines. The high freezing temperature of the substance made it possible to form a solid plug by cooling a process line with water or dry ice, and a method was developed for valving off lines by this procedure which made the use of mechanical valves unnecessary. The tendency of the material to form non-fusible reaction products made it necessary to clean scrupulously all items of equipment which were to come into contact with the process fluid. In order to keep the bottoms of the columns supplied with fresh feed material a circulation was maintained from the storage reservoir through steam jacketed nickel lines to the rack. The use of pumps was avoided by the use of convection loops in the closed circuits to supply a driving force. The columns were interconnected at the top and product was intermittently bled off from groups of columns into small nickel capsules. The hot wall of the column was heated with saturated steam at 1000 p.s.i., and the cold wall was cooled with water entering at a temperature of 150°F.

3. Design and Construction. - It was necessary to bring a new contractor into the Manhattan District for the S-50 construction job because no construction contractor already employed by the District was able to take on more work. The H. K. Ferguson Company was selected as the original construction contractor, because this company was regarded as most likely to finish the S-50 construction in the least amount of time. The contract was on a cost-plus-fixed-fee basis, stipulating that the company as architect-engineer-manager would do all things

necessary for completion of design, engineering, construction, and equipping of the proposed Liquid Thermal Diffusion Plant. The selection of the New Boiler Plant Construction contractor was made on the basis of availability. The H. K. Ferguson Company knew the design but lacked construction forces at that time and was given an architect-engineer contract. The J. A. Jones Construction Company, Inc., could provide necessary personnel, and was chosen as the construction contractor. Watt's Bar, Muscle Shoals, and Detroit were considered as possible sites, but the K-25 Power House area was chosen because of the apparent availability of steam and water. Location at the Power House was also desirable because it was within the area of the Clinton Engineer Works.

The fundamental design of the S-50 Plant was centered around drawings for a contemplated naval production plant which were turned over to the H. K. Ferguson Company. The plant was to be comprised of 21 identical copies of the 1000 p.s.i. steam-operated liquid thermal diffusion rack developed at the Philadelphia Pilot Plant of the NRL. In order to carry the construction forward as quickly as possible, much of the work was done from field engineering sketches. The severe tolerance specifications on the annular spaces of the columns, which were to be 0.010 plus or minus 0.002 inches, entailed great problems when it was attempted to put production of these items on a quantity basis. Twenty-three manufacturers were consulted before the Grinnell Company and the Mehring and Hanson Company agreed to attempt the job. These two companies succeeded in producing the large numbers of columns required after special precision techniques were developed. Next in

importance to the process fluid system was the process steam system. Steam delivered from the K-25 Power House at 1250 p.s.i. and 925°F, was to be desuperheated and throttled to 1000 p.s.i. within the S-50 plant. Three steam leads from the main steam header in the K-25 Power House were installed to feed three manifolds, each supplying seven racks. The condensate was collected in headers at the bottoms of the racks and returned to the boilers by means of three multi-stage centrifugal pumps, which also supplied the desuperheaters. These pumps were specially designed by Pacific Pumps, Inc., to handle the large quantities of nearly saturated condensate at 950 p.s.i. Auxiliary facilities consisted of drainage equipment, blowdown lines, and a receiving tank. The S-50 plant was designed to exploit the maximum steam capacity of the K-25 Power House; and when the output became limited by outages and increased K-25 power demands, plans were made for the construction of a New Boiler Plant. The design of the New Boiler Plant called for a change in column steam specifications in order to utilize surplus 450 p.s.i. boilers furnished by the Navy. The decrease in theoretical column capacity because of reduced hot wall temperature did not greatly affect overall production, because of greater ease of operation at the lower pressure. The New Boiler Plant consisted of twelve destroyer-escort boilers furnished by the Navy from surplus stock. These were originally designed by the Babcock and Wilcox Company to produce superheated steam at 750°F but were adapted to supply saturated steam at 450 p.s.i. This required changes in construction, principally the removal of economizers and superheaters. The installed capacity was 53,000 pounds per hour for each of the twelve

units. These boilers were oil-fired, and a critical oil situation necessitated the construction of a large tank farm capable of storing 6,000,000 gallons, which would be sufficient for 60 days operation. The cooling water system of the S-50 Plant supplied Clinch River water to the outer jackets of the columns. Four 15,000 GPM pumps were installed in a pump house to provide the racks with make-up water, which was maintained at an inlet temperature of 150°F and was continuously circulated through columns of the rack by means of centrifugal cooling water pumps.

The need for early production dictated severe construction schedules. A Main Process Building construction schedule of six months was considered optimistic; but a seventy-five day schedule, to begin operation, was adopted. Procurement of equipment during original construction was facilitated by high priorities without which the special equipment could not have been obtained in the short time required. The first order for columns was placed on 5 July 1944. Clearing of the site was begun on 9 July. By 16 September 1944, 69 days after the actual start of construction, one third of the plant was completed; and preliminary operation of the first rack was begun. On 15 February 1945 a stop order was issued to the H. K. Ferguson Company. Construction of the New Boiler Plant was approved on 16 February 1945. The first of the twelve boilers was fired on 5 July 1945, and steady operation began on 13 July. The New Boiler Plant was to be finished by 1 June, but unavoidable delays prevented its completion until 15 August 1945. The problem of labor procurement was a difficult one, since the S-50 site was in a critical labor area. Although the H. K. Ferguson Company supplied the top supervisory personnel, and their labor recruiters

worked with the U. S. Employment Service, labor requirements were never fully met. Enforcement of security was relatively simple because the S-50 Plant was located within the K-25 Area. An adequate safety organization was set up in the early days of construction, and the final safety report for the H. K. Ferguson Company was one of the best in the Clinton Engineer Works. As of 1 June 1946, design and construction costs amounted to $12,910,639.

4. Description of Plant. - The Main Process Building housed all the process equipment; the auxiliary buildings consisted of a pump house, laboratories, an administration building, a cafeteria, a time office, two boiler houses, a tank farm, a change house, a machine shop, warehouse, a gasoline filling station, a conditioning shop, a switch house, and a water treatment plant. The basic piece of process equipment was the isotope separation column, 102 of which were arranged to form one operating unit termed a rack. A process column was made up of a vertical 48-foot length of $1\frac{1}{4}$-inch nickel pipe surrounded by a copper pipe of such size that the annular space between the two was 0.250 mm. plus or minus 0.050 mm. Encasing the copper pipe was a water jacket of 4-inch galvanized iron. The nickel pipe was heated with 1000 p.s.i. steam, and the copper pipe was cooled with water at an average temperature of 155°F. Three nickel "tits" at each end of the column provided access to the annular space. For purposes of steam distribution, the racks were arranged in three groups of seven. Columns were connected in parallel at top and bottom by means of nickel "intercolumn connectors" for purpose of process fluid supply and withdrawal. In this manner each rack was subdivided into 2, 4, or 6 banks which, together with

the steam-jacketed nickel conduit lines, the convection loop, and the reservoir, formed the "circuit", which was the operational unit. Columns could be isolated from one another by means of freeze-off water flowing through copper tubing brazed to the intercolumn connectors. This served to form solid "valve-plugs" of material within the nickel lines. The reservoir was simply a jacketed storage container for process fluid, consisting of an 8 inch by 8 foot nickel cylinder equipped with an inner heating coil. It was mounted on scales and surrounded by armor-plate. Three reservoirs for each rack were located in the transfer room. The convection loop was a 48-foot inverted "U" formed of nickel tubing. One leg was heated with 5 p.s.i. steam, and the other with 150 p.s.i. steam. The resultant difference in density due to the difference in temperature between the legs, supplied the driving force for circulating material between the rack and reservoir. Most of the process control instruments were contained in the control room adjacent to each transfer room and serving two racks. Product withdrawal equipment consisted of two freeze-off coils, separated by a nickel metering capsule, and leading to a larger receiver capsule. By alternately unfreezing the coils, a measured quantity of product could be drawn off from the top of a circuit and delivered to the receiver capsule. Two assay laboratories were provided for control work, utilizing the mass-spectrometer and alpha-counter methods respectively.

The 1000 p.s.i. process steam equipment included desuperheater pumps, Venturi type desuperheating elements, throttling valves, and the necessary high pressure piping. The New Boiler Plant utilized twelve 450 p.s.i. boilers and the appurtenant boiler feed pumps, make-up pumps,

forced draft fans, condensers, an evaporator, a fuel oil system, a condensate system, piping, an automatic boiler control system, and miscellaneous equipment. The tank farm equipment consisted of oil storage tanks, pumping apparatus, Boiler Plant No. 2 for heating the fuel oil, and miscellaneous equipment such as piping and railroad tracks. The cooling water equipment included circulating pumps, make-up pumps, and piping. A water treatment plant which removed undesirable impurities from river water was operated in conjunction with the freeze-off water system. Other utilities consisted of a potable water supply, a sewage disposal system, steam heat, and electrical supply from the K-25 Power House. Main lines supplied the S-50 switch house in which a transformer converted the 13,200 volt supply to 2300 volts and 440 volts for power use. The lighting supply was tapped from the 440-volt system and transformed at the various buildings. Both rail transportation and water transportation were available to the S-50 area.

5. Operations. - It was the desire of the District Engineer that the H. K. Ferguson Company operate, as well as design and build, the S-50 plant. To eliminate the strong possibility of labor troubles in the H. K. Ferguson Company organization (which always operated on a closed shop basis) if non-union labor were hired as operations personnel in accordance with District policy, the Fercleve Corporation was formed; and the contract was split into separate construction and operation contracts. The Fercleve Corporation contract, W-7409-eng-100, was a cost-plus-fixed-fee contract, and the fee was set at $11,000 per month. Specifications on concentration of the product were laid down by the District Engineer at 120 per cent of the concentration of normal

material.

Personnel training began at the Philadelphia Pilot Plant in August 1944, but was cut short on 2 September by a disastrous explosion which seriously damaged pilot plant installations and injured several of the personnel. All of the Percleve trainees and fifteen NRL men under the supervision of P. H. Abelson immediately proceeded to the S-50 site, where preliminary conditioning of equipment was begun on 10 September 1944. Early conditioning and processing operations were hampered by construction work which was still in progress on the racks, by lack of pilot plant data, and by lack of trained personnel. On 30 October the first product was drawn off. However, because of many handicaps, large scale production was not attained until January 1945, when 10 out of 21 racks were producing. The number of racks in operation increased continually, and by 15 March 1945 all 21 racks were yielding product. Improvement in operating techniques and stabilization of steam supply resulted in additional increases in production until a peak was reached in June. Curtailment of steam from the K-25 Power House and the difficulties involved in changing seven racks to a 450 p.s.i. steam supply sharply reduced production from 1 July to the final shut-down in September 1945.

The operation performed in processing the material consisted of circulating uranium hexafluoride from the reservoir in the transfer room, through a conduit line to the rack, where it passed through a convection loop and across the bottom of a series of columns, and then back through another conduit line to the reservoir. In this manner

feed was provided for the columns, where the separation of isotopes took place. In order to maintain a constant supply of fresh material to the columns, it was necessary to eliminate all restrictions and obstructions to flow through all parts of the material circuit, which was made up of a series of 1/16 and 3/32 inch diameter lines and passageways. To prevent the accidental plugging of the circuit by solidification of process fluid, it was necessary to keep all parts of the circuit above 155°F. This was done by enclosing all lines and connections in steam-heated ducts. Obstructions resulting from contaminating particles of copper or nickel, or the reaction products of the material with moisture or organic matter, were removed by replacing the item in question, after locating the obstruction by means of a pressure-variation technique. Occurrence of this type of obstruction was minimized by rigorous conditioning of all process equipment prior to use. This procedure called for thorough cleaning of all dirt and scale with special emphasis on the removal of grease and moisture. It consisted principally in treating with organic solvents and hydrochloric acid, rinsing with water, and drying completely by flushing with dry nitrogen and evacuating at high temperature. The final step was fluorination, which removed last traces of moisture and formed a protective fluoride film on metal surfaces. Another function of the operating personnel was the prevention of intercolumn circulation, which was an effect noted when two or more adjacent columns were connected together at both top and bottom. This could occur if the intercolumn connections were accidentally thawed by failure of freeze-off water. When this happened, slight differences in material temperature in adjacent columns resulted in a convective

flow of process fluid up one column and down the next which was ruinous to rack production. A constant check was maintained at all times to prevent such an occurrence. The next important factor in routine operation was the prevention of "pitching". This was a rather violent boiling or bubbling phenomenon which occurred when the pressure of the process circuit was unintentionally permitted to drop below 1200 p.s.i. It resulted in a turbulent mixing action which interfered with the slow and orderly diffusional accumulation of enriched material. The normal process pressure of 1500 p.s.i. was maintained by regulation of the steam supply to the reservoir at a proper value dependent upon the material content of the vessel.

Raw material was received from the Harshaw Chemical Company of Cleveland, Ohio, in nickel shipping containers, and was introduced into the process by addition to the reservoirs in the transfer rooms. Various types of difficulties such as plugging of the process system occasionally necessitated the withdrawal of material, which was accumulated in containers and returned to the process system as feed material. When mechanical or operational failures occurred, material was also lost to the atmosphere or cooling water. After a certain period of time, during which the feed material was circulated along the bottoms of the columns, the reservoir was emptied of its material, and this depleted material was then shipped to the K-25 Area. The enriched product of column action was removed periodically from the tops of the columns by means of the milking equipment and was sampled, blended, and shipped to Y-12 or K-25 for further enhancement. The Product Control Section scheduled all product withdrawal, utilizing assay

information to maintain quantity and quality at an optimum. The Process Control Section ran material balances on the plant, issued control data and efficiency ratings for the various units, maintained production records, and made production estimates. Of primary importance to product and process control were the assay laboratories. Laboratory No. 1 determined the concentration of Uranium-235 by the relatively rapid mass spectrometer method. Laboratory No. 2 more accurately analyzed samples by counting alpha particle emission. The Materials and Conditioning Shop supplied operations with process material, prepared equipment for use in the production units, and disposed of material and equipment received from operations. Steam Department operations increased in scope from the originally planned control of desuperheating and pressure reducing equipment, to eventual control of all utilities necessary for plant operation.

The major problem, caused at the outset by insufficient steam supply from the K-25 Power House was aggravated by further unexpected troubles there. High pressure steam leaks, at the unions which connected the columns to the steam and condensate headers, constituted a problem which was solved only by substitution of welded pipe nipples for the unions. Various other design changes in the steam system resulted in greater efficiency. The shortage of qualified operations personnel was greatly relieved by the assignment of technically trained enlisted men from the Special Engineer Detachment and the use of several men from the Naval Research Laboratory. The industrial relations department of the Fercleve Corporation administered such affairs as employment, wages and hours, housing, schooling of employees, and transportation.

Security was maintained by close cooperation of the Fercleve Corporation Security Division with the District Intelligence and Security Offices.

Studies by the District Product Control Section, with a view to determining the most efficient method of utilization of the various separation plants and combinations thereof, led to the decision that, with Y-12 and K-25 in full operation, the entire first stage of separation could most efficiently be handled by the K-25 Plant. Therefore, on 4 September 1945 orders were issued to terminate all operations at S-50 and to place the plant in standby condition. By 9 September all racks were shut down. On 18 September termination of all employees not essential to the work of placing the plant in standby was begun. On 16 February, 1946 the last employee was terminated, and the acting project manager departed. The entire area was subsequently transferred to the custody of the K-25 Operations Officer. Records were disposed of in accordance with District procedures. As of 1 June 1946, total S-50 operating expenditures were estimated by the District Cost Section at $6,992,616.

6. Organization and Personnel. - Because of the research previously conducted by the Naval Research Laboratory, the personnel of that organization co-operated extensively with the S-50 Project. Dr. P. H. Abelson, Head of the NRL Special Research Division, perfected the liquid thermal diffusion method; and, with the aid of fifteen NRL men, assisted greatly in initial S-50 operations. Colonel K. D. Nichols, C.E., was District Engineer and Contracting Officer. Lt. Colonel M. C. Fox, C.E., was assigned to the S-50 area as Unit Chief from 25 June 1944 to 31 March 1945, when he was succeeded by Major Thos. J. Evans, Jr.,

C.E. Enlisted personnel of the Special Engineer Detachment, 9812th Technical Service Unit, were assigned in various technical capacities, and contributed greatly to the successful operation. W. N. Thompson was Chief Engineer for the H. K. Ferguson Company, and C. W. Roberts was Project Manager. Mr. Roberts was also General Manager for the Fercleve Corporation which was a totally owned subsidiary of the H. K. Ferguson Company, organized for the purpose of operating the S-50 Plant. R. S. Lamie was Production Superintendent, and Dr. B. F. Dodge was Director of the Technical Division. The H. K. Ferguson Company payroll reached a peak of 1900 construction workers in September 1944. The Fercleve Corporation payroll reached a peak of 1600 operating people in April 1945.

MANHATTAN DISTRICT HISTORY

BOOK VI - LIQUID THERMAL DIFFUSION (S-50) PROJECT

SECTION 1 - INTRODUCTION

1-1. Purpose. - The original purpose for which the S-50 Project was created was to provide the Electromagnetic (Y-12) Project (Book V) with feed material in which the concentration of Uranium-235 had been increased above the natural concentration, until such time as the Gas Diffusion (K-25) Project (Book II) could begin to produce large amounts of high concentration feed.

1-2. Scope. - The scope of the S-50 Project included the design, construction, and operation of a liquid thermal diffusion plant capable of accepting as feed, uranium hexafluoride (UF_6), in which the isotopic concentration of Uranium-235 was 0.71 atom per cent, and yielding product in which the amount of Uranium-235 had been raised from this natural concentration to about 0.85 per cent (Par. 2-4). The S-50 Project reached its operation peak during the month of June 1945.

1-3. Authorization. - All action in connection with the institution and prosecution of this project was taken under authority granted by Congress in the Acts which are described in Book I; the funds used were likewise appropriated by Acts there described. Under the authority vested in him by these Acts, the President issued orders and authorizations which are also outlined in Book I, Vol. 17. Major General L. R. Groves thereupon authorized the general policies and directives under which the Manhattan District carried out the work.

1-4. Selection of Process. - In June 1941 the Naval Research Laboratory started research on the process. First the National Defense Research Committee, and, later, the Office of Scientific Research and Development S-1 Committee were kept informed of the progress being made in the development (Par. 2-3) of the Liquid Thermal Diffusion Process for concentrating Uranium-235 (App. G15). Viewed in the light of early overall Manhattan District objectives, the method seemed less promising than other methods under consideration because of the long equilibrium time which was believed necessary for the separation. The NRL, however, having a different and more limited objective than the S-1 Committee independently developed the process. Although there was no formal relation between the NRL group and the S-1 Committee of the OSRD, members of the S-1 Committee and individuals and groups associated with that committee had occasion, from time to time, to review the progress being made by the NRL (App. G16, G17, G18) and to assist the NRL by supplying material and furnishing assay service. By June 1944 it had become apparent that the Liquid Thermal Diffusion Process could be used to great advantage in a preliminary stage as a means for producing a feed material of somewhat enriched concentration, and this process was included among those already in use by the Manhattan District.

1-5. Summary of S-50 Costs. - The following is a summary of the S-50 Project costs (see also App. D5 and D6):

a.	Research. (Research cost was borne by the Navy.)	
b.	Design and Construction.....	$12,910,639
c.	Operation.....	6,992,616
d.	Total Manhattan District Expenditures.....	19,903,255

SECTION 2 - RESEARCH AND DEVELOPMENT

2-1. Basic Theory. - The basic theory of the liquid thermal diffusion process involves a combination of two factors: first, the factor of thermal diffusion, which in many liquid mixtures causes a concentration of one component near the hotter of two surfaces; and second, the factor of convection, which can be used to make this separation more effective by utilizing the principle of counter-current flow. In other words, if a mixture of two liquids is placed in a closed container which has one hot wall and one cold wall, the phenomenon of thermal diffusion causes the concentration of one component, say the lighter component, near the hot wall; and then the ordinary process of convection carries this more concentrated liquid upward. This means that as time goes by, a concentration gradient will build up not only horizontally but also vertically, since the liquid near the hot wall is continually being replaced by the convectively carried lighter component. The result is that the liquid at the top of the column is richer in lighter component than that at the bottom. Thermal diffusion apparatus (called a column) actually consists of a long externally cooled tube, with a hot concentric cylinder on the inside. The liquid is allowed to remain in the annular space* between these tubes for some time until the two processes result in a difference between the concentrations of the light component at the bottom and at the top of the column. By keeping the concentration of the lighter component at the bottom essentially that of raw material, the maximum concentration of the lighter component is obtained at the top. However, since the heavy component tends to go to the bottom of the column and lower the

concentration of lighter component there, it is necessary to flush out the bottom of the column continually with raw material.

2-2. Development of Theory.

a. Theoretical Discovery of Phenomenon. - The phenomenon of thermal diffusion in gases was first discovered theoretically by Enskog (App. F1) in 1911 and independently by Chapman (App. F2) in 1916. Their theoretical considerations showed that a gradient of temperature existing in a gaseous mixture produces a motion of relative diffusion of the constituents additional to and independent of any diffusion resulting from other causes such as concentration gradients. If a constant temperature gradient be maintained in a closed vessel, when a steady state is reached, a concentration gradient will have been established such that the rate of diffusion due to concentration gradient balances the opposing rate of diffusion due to temperature gradient, i.e., thermal diffusion.

b. Experimental Confirmation. - Qualitative confirmation of the theory of thermal diffusion in gases was first obtained in 1917 by Chapman and Dootson (App. F3), who filled two bulbs with the same homogeneous mixture of gases, connected the bulbs with a capillary tube, and then maintained the bulbs at different temperatures; after a time, analysis showed different compositions of the gas mixture in the two bulbs.

c. Invention of the Thermal Diffusion Column. - Clusius and Dickel (App. F4) in 1938 devised an effective method of fractionation by running a heated wire along the central axis of a long, vertical tube, into which was placed the gaseous mixture whose constituents were

to be separated; the combination of the effect of thermal diffusion and of the convection currents set up in the tube was such as to increase greatly the rather small separation caused by the radial temperature gradient; one component collected at the top while the other component went to the bottom of the column. Bramley and Brewer in 1939 (App. F5) modified the apparatus by using two large concentric cylindrical members, one heated and the other cooled.

d. Thermal Diffusion in Liquid Solutions. - Ludwig (App. F6) found in 1856 that, when differences of temperature are maintained in a salt-solution, the disolved material will concentrate in the cooler portions of the liquid. This phenomenon, long known as the Soret effect*, but never explained theoretically, was recognized by Chapman in 1929 (App. F7) as the liquid counterpart of gaseous thermal diffusion. Korshing and Wirtz (App. F8) as well as Clusius and Dickel (App. F9), found that an appreciable separation of the constituents of liquid solutions can be made by these methods.

e. Separation of Isotopes. - Isotopes are forms of a chemical element which are identical in chemical behavior and distinguishable only by radioactive transformations or small differences in atomic weight. The use of thermal diffusion for separating isotopes was first suggested by Chapman (App. F10) in 1919. Clusius and Dickel were the first to employ liquid thermal diffusion in isotope separation, and they succeeded, in 1939 (App. F9), in obtaining a small separation of the isotopes of hydrogen by using water as a working substance. Using a water solution of zinc sulphate, Korshing and Wirtz (App. F11) succeeded in effecting a separation of zinc isotopes. No work on liquid thermal

diffusion had been published in this country up to July 1940, at which time the interest of Dr. P. H. Abelson was first aroused (App. G1). Abelson at that time was employed by the Carnegie Institution of Washington. Since the laws governing the phenomena of liquid thermal diffusion had not been systematically investigated, a program was undertaken at the Carnegie Institution of Washington to survey these laws and to investigate the possibilities of separating uranium isotopes by means of thermal diffusion (App. G2).

2-3. Development of Operating Process. - Ever since the discovery of uranium fission* the Navy was anxious to explore the possibilities of utilizing atomic power. From the beginning, the Naval Research Laboratory was actively interested in Abelson's experiments (App. G3); and, in September 1940, the Laboratory entered into a contract with the Carnegie Institution of Washington providing $2500 to enable the experiments to be continued and expanded (App. G4). In October 1940, the experiments were moved to the National Bureau of Standards (App. G5). This arrangement continued until 1 June 1941, when Abelson entered the employ of the Naval Research Laboratory, pursuing the study of liquid thermal diffusion separation of uranium isotopes (App. G6). By 1942 a pilot plant using low pressure steam was erected at the Anacostia Naval Station by the NRL. A high pressure steam pilot plant was constructed by the NRL in the Philadelphia Navy Yard in 1944. The Naval Research Laboratory carried out the research and development necessary for the construction of S-50; and, in the naval pilot plants, equipment was designed and tested, and an operating technique was developed.

a. Preliminary Development. - Between 1 July 1940 and 1

June 1941 eleven liquid thermal diffusion columns were constructed at the National Bureau of Standards, and water solutions of potassium salts were employed in these columns. The solutions were placed in the annular space between two concentric pipes, the inner pipe being steam heated and the outer one being water cooled. A third concentric pipe encased the cooling water and formed the outside jacket of the columns. The lengths of these pipes ranged from 2 to 12 feet, with an annular diameter of approximately $1\frac{1}{2}$ inches; several different annular spaces were used ranging from 2.0 mm. to 0.5 mm. Through the use of these columns, the separation factor* and the relaxation time* were measured as a function of length, wall spacing, and temperature difference between the hot and cold walls. The crucial variables proved to be temperature difference and, especially, wall spacing. This latter variable, when changed by a factor of 2, caused the relaxation time to vary from a few minutes to many hours. It is of interest to note that later research has shown that the findings on water solutions have very limited application to the study of what occurs when UF_6 is used as a working substance (App. G7). However, the use of salt solutions did point to the variables which might prove important, for, at the beginning of the research, an insufficient amount of UF_6 was available to test the method.

b. Selection of Working Substance. - After the research on potassium salts was completed, an attempt was made to apply the columns to the isotope separation of water solutions of uranium salts. This proved to be quite hopeless because all water solutions of uranium salts tended to decompose at the surface of any practicable wall materials. In addition, there was the problem of overcoming the relative change in con-

centration between top and bottom fractions. As the work progressed, it became increasingly clear that to be practicable, the working substance in the liquid thermal diffusion apparatus must be a single stable compound. The sole uranium compound which might work was uranium hexafluoride, UF_6. However, no supply of this material was available and up to that time only a few grams of the substance had ever been prepared. Abelson devised a new method suitable for large scale production, which consisted of preparing uranium tetrafluoride, UF_4, by an ordinary wet chemical method, drying it, and converting to UF_6 by fluorinating at 350° C (App. G8). When a few kilograms had been prepared, preliminary experiments to test vapor pressure, stability, and corrosiveness of the substance were carried out. UF_6 was then introduced into two thermal diffusion columns and runs were made. Results which appeared to be positive were obtained but later experiments seemed to indicate that the analysis of the mixtures which was performed by Alfred O. C. Nier and L. F. Curtiss (App. G9) might not be correct, since these men were just beginning to make the uranium isotope analysis and the results were very little different from zero.

c. High-Temperature Experiments. - About 1 June 1941 the decision was made by Naval officials to pursue the study of liquid thermal diffusion, using 36-foot columns, at the Naval Research Laboratory (App. G10). It was felt that a number of columns with various spacings should be built and that these columns should be tested at temperatures as high as, or even higher than, the critical temperature* of UF_6. For this purpose a 20-horsepower, high pressure, gas fired boiler was ordered and ultimately installed at the Anacostia Naval Station. This unit proved to

be capable of delivering 750 pounds of steam per hour at a pressure of 600 p.s.i. Because of various delays on the part of the suppliers, the equipment was not completed until 1 November 1941. At this point valuable time was lost when an experiment was performed using carbon tetrachloride as a working substance in the column. Positive results were obtained showing separation in the chlorine isotopes and the effect could be easily measured by a change in density which occurred. It was found that the light fraction differed in density by one part in 200 from that of the heavy fraction. However, accompanying the separation was a decomposition of carbon tetrachloride and ultimately it was found that the column had been ruined, since it was impossible to clean out the heavy solid decomposition products of carbon tetrachloride (App. G-10). It was therefore necessary to construct a new column using a wall spacing of 0.53 mm. This new column was completed about 1 January 1942. Having been given the necessary preliminary conditioning treatment, the column was placed in operation, using UF_6 as a working substance. The reports of analysis of samples from this device were obtained about 1 February 1942, and showed a separation of two percent. This was the first time positive results were obtained. Further experiments with the column yielded a $2\frac{1}{2}$ percent separation.

d. Determination of Optimum Dimensions. - While these tests were in progress, a new column was constructed at the Anacostia Naval Station, which employed an increased spacing of 0.65 mm. It was put into operation 1 March 1942, and numerous runs were made with it under varying conditions. These runs yielded a maximum of 1.4 percent separation. Prospects that liquid thermal diffusion might be of value for large scale

separation of uranium isotopes seemed dark indeed at this point. However, a third column was placed in operation employing a spacing of 0.38 mm. The first results from this were forthcoming on 22 June 1942. These showed a separation of 9.6 per cent and indicated that by decreasing the spacing between the hot and cold walls to a somewhat smaller value, still better results might be obtained. One of the encouraging features was the fact that the time necessary to obtain substantially an equilibrium separation was two days. At this point, it is convenient to introduce what Dr. Abelson calls a "pseudo-equilibrium time" (defined as the time required for the apparatus to produce a separation equal to one half of the equilibrium value). The pseudo-equilibrium time for this new column was 8 hours, and in spite of the increased separation that was obtained, this time was not greater than that found in the columns possessing a wider spacing (App. G11). During July another column was placed in operation having a spacing of 0.21 mm. and this led to a separation factor of 21 per cent. During September another column was tested with a spacing of 0.14 mm. The results from this apparatus clearly indicated that the optimum spacing was greater than this value since the separation factor fell to 12.6 per cent, and the pseudo-equilibrium time amounted to approximately 13 hours. It was felt that although the optimum spacing had been bracketed between 0.21 and 0.38 mm. (App. G12), the best one had not yet been determined. Indeed, evidence suggested that optimum spacing was a function of hot wall temperature, and tests were continued to determine optimum spacing and hot and cold wall temperatures using 36-foot experimental columns.

e. Pilot-Plant Research. - By 1 August 1942 it had become

clear that the erection of a pilot plant was desirable. The use of a single column to get all the information that was needed for design of a large plant required too much time. Furthermore, it was felt desirable to gain experience in the method of connecting columns in series and to obtain experimental evidence on the pseudo-equilibrium time as a function of the number of columns connected in series. In addition, the permissible rate of product withdrawal was desired. The pilot plant was expected to provide information as to the dependability of the units and the feasibility of operating a large plant with a minimum of difficulty. By 15 November, the plant at the Anacostia Naval Station (App. G13) was in a practically completed state and the first tests were begun. In the period between 3 December and 17 December 1942, the apparatus was run continuously with no shut-down or break-down whatsoever. Indeed, so constant were the various temperatures and operating characteristics that practically no attention was required to insure successful operation. In order to reduce the equilibrium time and thereby increase the rate of production, an increase in the temperature gradient was necessary. This factor complicated subsequent design in two principal ways. Primarily, in order to increase this temperature differential, a vastly increased steam pressure was needed. The increased temperature further necessitated a corresponding increase in the material pressure to prevent "pitching" (Par. 5-5a). However, by June 1944 the Naval Research Laboratory had nearly completed a high pressure steam Pilot Plant in the Philadelphia Navy Yard and had planned operating procedure to an advanced degree. By sending trained personnel to the S-50 site to assist in starting operations, the Naval Research Laboratory transferred its Pilot Plant knowledge

to the S-50 Project.

f. Production Plant Development. - The operations contractor for the S-50 plant, the Fercleve Corporation (Par. 5-1), also carried on extensive surveys through its Technical Division. In these surveys, sufficient data were gathered to improve the process and to make decisions in questions of operating procedure, particularly with regard to schemes for connecting columns, optimum rate of product removal, and enrichment at which product should be removed. In addition tests and experiments were performed on pieces of equipment such as columns, fittings, etc., in order to improve the operating process (App. G32). Such subjects were investigated as rate of flow of process fluid through circuits, stress corrosion of nickel welds, pressure measurements, effect of material pressure on column performance, and identification of plug-forming materials.

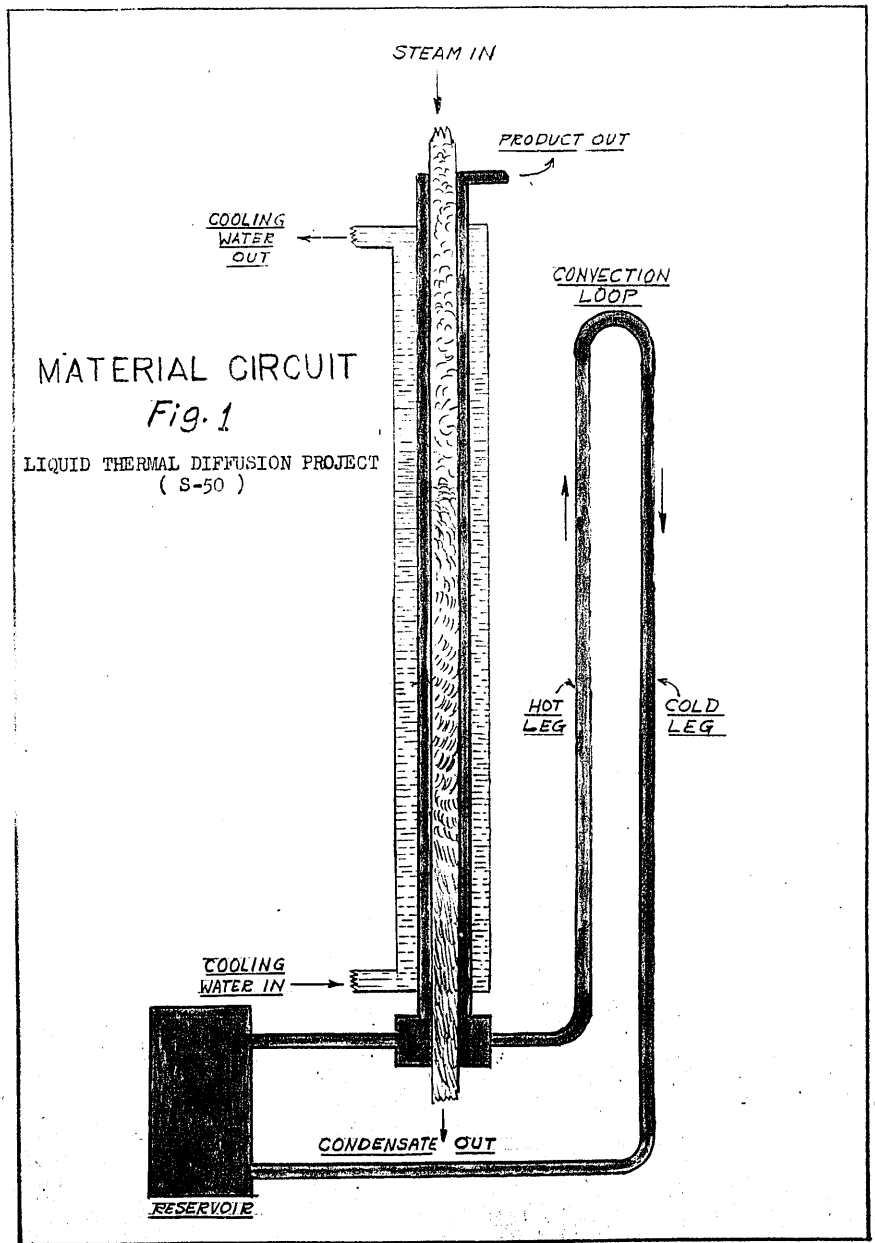
g. Further Process Studies. - The Naval Research Laboratory is continuing research on thermal diffusion separation of uranium isotopes. Primarily, it is engaged in improving column performance, and this has been attempted in three ways. First, the relative advantages of "single stage" and "pyramid" methods of connection of liquid thermal diffusion columns have been investigated. Second, gaseous thermal diffusion columns have been manufactured and tested to determine relative merits of gaseous and liquid thermal diffusion separation of uranium isotopes. However, under one atmosphere pressure with 545° F hot wall and 155° F cold wall, no separation was detected and it was believed that experimental conditions would have to be altered quite radically to produce a significant separation. Third, unconventional columns, such as columns with extremely

small wall spacings were tested. Results thus far have shown that a perfectly fabricated column with optimum wall spacing has not yet been achieved. For example, further hardening of the inner nickel tube is necessary, and improved welding technique is desirable in order to produce a column with minimum internal stress. The Philadelphia pilot plant has been shut down because it was felt that an installation on this size was no longer necessary to carry on present research. However, work is being continued in the Naval Research Laboratory at Washington, D. C.

2-4. Description of Process. - Uranium exists naturally as a mixture of three isotopes. One of the isotopes, known as Uranium-235, has a different tendency toward radioactive disintegration* than the others, and if separated from the other isotopes it is cabable of producing enormous explosions. Uranium isotopes are always found in nature mixed in the same ratio, and Uranium-235, the highly desired isotope, comprises about 0.71 per cent of the total mixture, Uranium-238 accounts for about 99.28 per cent and the remainder is Uranium-234; since Uranium-234 exists as such a small percentage (0.006 per cent) its existence will be disregarded from this point on. The S-50 process obtained as product an "enriched" mixture of uranium isotopes in which the percentage of Uranium-235 had been raised from 0.71 per cent to about 0.852 per cent and discarded as waste a "depleted" mixture in which the Uranium-235 content had been lowered to about 0.67 per cent. It should be noted, however, that while this was the method of operation at S-50, it is possible to recycle the material and produce considerably greater separation, sacrificing quantitative production accordingly. The principal drawback to attempting a complete separation within the S-50 Project was the enormous steam re-

quirement of the Liquid Thermal Diffusion Process.

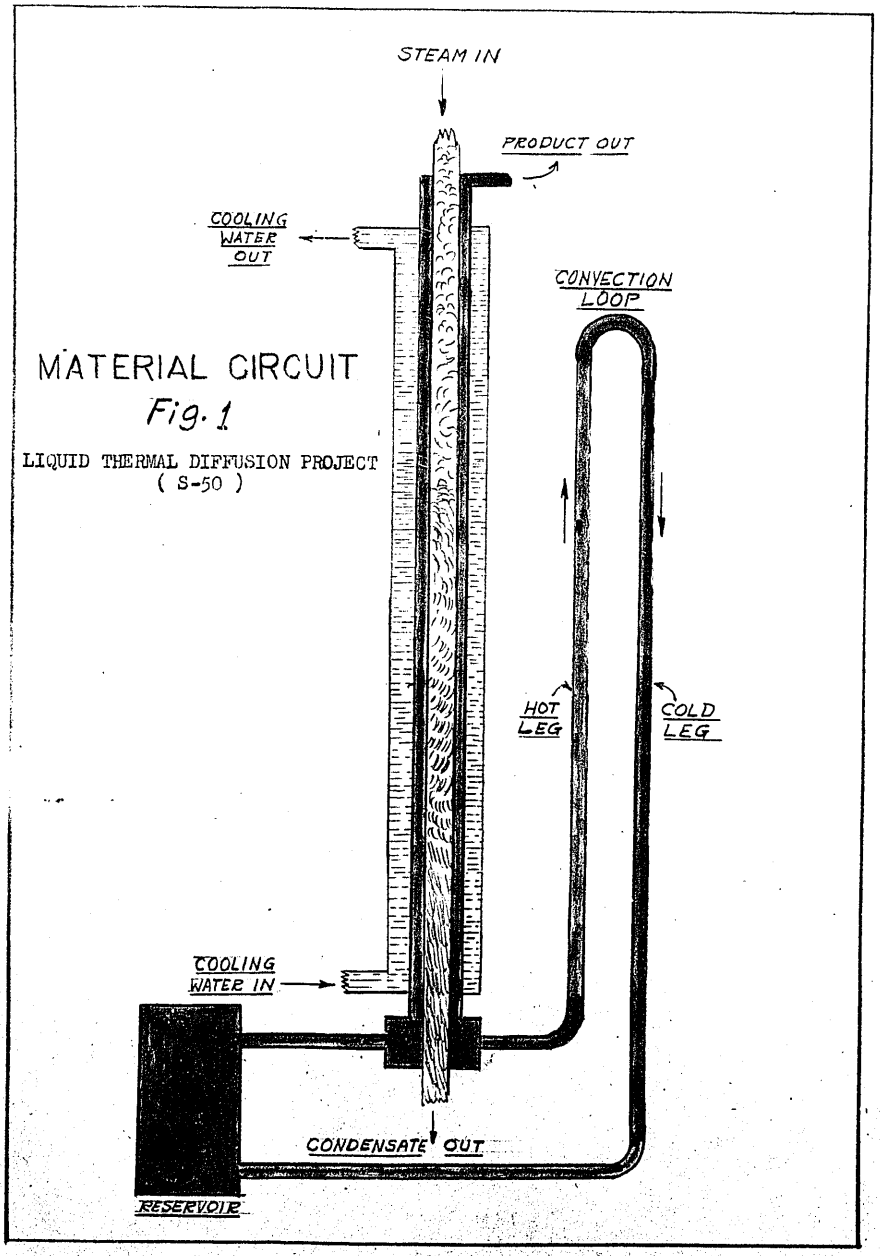
a. Process Material. - The actual substance which was used in the S-50 operation was uranium hexafluoride, a stable fluorine compound of uranium, which has the chemical symbol UF_6. In a molecule of UF_6, six atoms of fluorine are combined with one atom of uranium, which in a random case may be either a heavy or a light isotope of uranium, i.e., either Uranium-238 or Uranium-235. S-50 obtained a partial separation of these isotopes of uranium by using UF_6 as a working substance in precisely the same manner that Clusius and Dickel obtained a small separation of the isotopes of hydrogen by using H_2O as a working substance (Par. 2-2e). Uranium hexafluoride is a white crystalline solid at room temperature and normal barometric pressure, but it sublimes as the pressure is reduced or the temperature increased. For example, it will completely change to gas if the temperature is raised to 140°F. It will also change to gas at 85°F if the pressure is reduced to less than one-fifth of an atmosphere. At higher temperatures and pressures the hexafluoride exists as a liquid. In going from the solid at room temperature to a liquid at the melting point, the volume is increased by about 35 percent, and this unusually high change in volume determined the limiting conditions in many operations at S-50. The critical temperature of UF_6 is 450°F. Under the S-50 operating pressure of 1500 p.s.i., UF_6 melts at about 155°F. Therefore, all points in the process system were maintained at temperatures higher than 155°F to keep the material in a fluid state so that it could be circulated through the tubes and pipes. Within the annular space of the column in the region adjacent to the inner nickel wall, which was heated by steam at a temperature of 545°F, the process material was in the gaseous state. In



MATERIAL CIRCUIT

Fig. 1

LIQUID THERMAL DIFFUSION PROJECT
(S-50)



MATERIAL CIRCUIT

Fig. 1

LIQUID THERMAL DIFFUSION PROJECT
(S-50)

the region adjacent to the outer copper wall, which was cooled by water ranging in temperature from 150 to 160°F, the material was in the liquid state. Proceeding radially from cold wall to hot wall, the state of the process fluid can be visualized as passing through the transition region without separating into two phases but continuously losing the properties of a liquid, and gradually and imperceptibly taking on the properties of the gaseous state. This continuous single-phase transition was possible because of the high operating pressure, 1500 p.s.i., which exceeded the critical pressure* by some 600 p.s.i. UF_6 reacts with organic compounds, and most metals. Because of its affinity for water and organic compounds, elaborate precautions were taken to prevent any moisture, oil, or grease from entering the process system. The extremely corrosive nature of UF_6 necessitated the use of pure nickel for all material lines and furnished a strong reason for not using metal valves in the system. By utilizing the relatively high freezing temperature of UF_6, a solid plug of UF_6 could be formed by merely cooling the process line at the desired point with water or "dry ice", and this plug acted in effect as a novel valve.

b. Material Feed and Withdrawal. - The UF_6 was circulated through a closed circuit (Fig. 1) from the reservoir, through the bottom of the column and back to the reservoir. In this way the concentration (of the lighter molecule) at the bottom of the column was kept essentially the same as in the reservoir. When the material in the reservoir had been appreciably depleted, it was replaced with raw material. The circulation was effected by a convection loop (Par. 4-2d), the legs of which were maintained at different temperatures. Enriched material was inter-

mittently bled from the tops of the columns into a capsule, as illustrated in Fig. 4 (facing p. 4.5). The columns were connected together at the top by nickel tubes in order that all the columns in the circuit might be bled at once.

c. Process Steam. - The purpose of the process steam was to supply heat to the process columns in an economical, efficient manner, in large quantities and at constant temperature. The Naval Research Laboratory determined that saturated steam at 1000 p.s.i. and 545°F was desirable for the process. The steam entered the columns at the top (as shown in Fig. 1), condensed on the inner wall on the way to the bottom of the column, and passed out as saturated condensate at 950 p.s.i. and 535°F.

d. Cooling Water. - The purpose of the cooling water was to absorb and carry away the heat transferred from the steam through the column, thereby maintaining desired temperature conditions for efficient operation. The cooling water was pumped up through the outer 4 inch jackets of the columns, increasing in temperature from 150° upon entering to 160°F upon leaving.

SECTION 3 - DESIGN AND CONSTRUCTION

3-1. Introduction.

a. Selection of Original Construction Contractor. - The value of the proposed Liquid Thermal Diffusion Plant was directly dependent upon the length of time it could be operated before the larger K-25 Plant could be brought into operation. It is apparent, therefore, that although great dispatch was a prime requisite of all Manhattan District projects, speed was the very essence of the S-50 construction. Because of security and for other reasons, it was desired to avoid bringing another construction contractor into the project; but no contractor already engaged in Manhattan District construction could efficiently take on more work. The entire field of reliable construction contractors was therefore surveyed, and it was the consensus of the War Department officials concerned (App. D1) that the H. K. Ferguson Company of Cleveland, Ohio, would make the most vigorous attempt to complete the S-50 construction in the extremely short time required. The H. K. Ferguson Company was thereupon selected by Major General L. R. Groves, and negotiations were conducted for the design and construction contract.

(1) Original H. K. Ferguson Company Contract. - The H. K. Ferguson Company was given notice to proceed with the design and construction of the S-50 Plant by means of letter contract No. W-7409-eng-23 dated 27 June 1944. A formal contract was subsequently awarded. This prime contract was on a cost-plus-fixed-fee basis, stipulating that the company, as architect-engineer-manager, should furnish all labor, materials, equipment, and services not supplied by the government, and do

all things necessary for the quickest possible design, construction, and equipping of the S-50 process building and accessory facilities. The H. K. Ferguson Company was to build a plant comprised of twenty-one identical copies of the 1000 p.s.i. steam-operated thermal diffusion rack which had been developed by the Naval Research Laboratory in their Philadelphia Pilot Plant.

(2) Subcontracts. - A list of subcontractors under the original H. K. Ferguson Company contract, including their contract numbers, amounts and types of contracts, scope of work, and dates, may be found in Appendix C6 through C15.

b. Selection of New Boiler Plant Construction Contractors. As explained in Par. 3-6a, the S-50 Plant was designed to exploit the maximum steam capacity of the K-25 Power House; when the supply to S-50 became limited by outages, and because of increased power demands of K-25, plans were made for a new boiler plant to relieve the steam shortage. The H. K. Ferguson Company was selected as the architect-engineer because of that company's knowledge of the process plant design, power requirements, etc. The H. K. Ferguson Company, however, was not awarded the manager-construction work, because their original construction contract had been terminated, and the construction forces had been moved elsewhere before the decision was made to build the New Boiler Plant. The J. A. Jones Construction Company, Incorporated, was selected to handle the manager-construction part of the job, because this company was engaged in other construction work on the adjacent Gaseous Diffusion (K-25) Project (Book II, Vol. 4), and had adequate construction forces available. This made it possible to keep overhead expenses as low as possible.

(1) Second H. K. Ferguson Company Contract. - Under the cost-plus-fixed-fee Contract No. W-22-075-eng-58 (App. C1), the H. K. Ferguson Company was to render architect-engineer services in connection with the construction of a boiler plant, complete with equipment, within the area of the S-50 Plant, including the procurement and expediting of necessary material and equipment, and the engineering supervision at the site of the work. The letter contract, dated 15 February 1945, authorized the H. K. Ferguson Company to proceed with the design and procurement.

(2) J. A. Jones Construction Company, Inc., Contract. Under modification No. 6 of the cost-plus-fixed-fee Contract No. W-7421-eng-11 the J. A. Jones Construction Company, Inc., contracted to render the manager-construction services for the New Boiler Plant. The agreement specified that they would unload, handle, and erect all equipment, and perform all work necessary for the construction of the S-50 Boiler House and Tank Farm, with the exception of certain piping and electrical work specified in contracts with other companies. Further information with regard to the dates, amounts, etc., of the contract may be found in App. C2, and a resume of the original J. A. Jones Construction Company, Inc., contract may be found in Book II, Volume 4.

(3) Minor Contracts. - The A. S. Schulman Electric Company agreed to furnish the complete electrical system for the New Boiler Plant and auxiliary installations under Modification No. 6 of the cost-plus-fixed-fee Contract No. W-7405-eng-101. The Wm. A. Pope Company contracted to install the complete piping system in connection with the erection of certain oil storage tanks, Boiler House No. 2, and auxiliary pump houses under Modification No. 4 of the cost-plus-fixed-fee Contract

No. W-7405-eng-100. (See Book II, Volume 4 for a resume of these two original contracts.) The Grinnell Company, Inc., contracted to perform the piping work for the New Boiler Plant and certain auxiliary tanks under the lump-sum prime Contract No. W-22-075-eng-77. A list of these three minor prime contractors (less than $500,000), and two subcontractors, including their contract numbers, amounts and types of contracts, scope of work, and dates, may be found in App. C3, C4, C5, C16, and C17.

3-2. Naval Research Laboratory Design. - The column, in which the essential process of the plant took place (Par. 4-2a), was designed by the Naval Research Laboratory in the period 1940 to 1944. The width of the annular space between the two concentric cylindrical members of the column was a most critical dimension. The size decided upon for the S-50 Plant, 0.25 mm., was the result of several years' research. Later evidence shows that the dimension can be even further modified so as to improve column performance. Because of the temperature difference between the hot nickel tube and the cold copper tube, extreme stresses are set up within the column. This engineering factor, coupled with the fine tolerances in the required annular space, posed serious engineering difficulties. The Naval Research Laboratory, however, developed columns which performed very satisfactorily. Their columns were made one by one, in the fashion of piece work, using precision methods in the Philadelphia Navy Yard. At the time that the H. K. Ferguson Company was selected for the construction of the S-50 Plant, the Naval Research Laboratory had several columns in operation, and had designed and started construction of a rack (Par. 4-2b) utilizing 1000 p.s.i. steam.

3-3. Site Selection.

a. Reasons for Selection. - The selection of a site for the proposed S-50 Plant was controlled by the availability of steam and water. Several places were considered where steam plants existed, including Watt's Bar and Muscle Shoals of the TVA system; Detroit, Michigan; etc.; but investigation showed that the only place where sufficient steam was believed to be available was at the location of the K-25 Power House; that is, sufficient steam would be available until such time as the K-25 Plant was ready for operation. In view of the original purpose of the S-50 Plant, this temporary supply was believed satisfactory.

b. Location. - The K-25 Power House is operated for the Government by the Carbide and Carbon Chemicals Corporation (App. C41) and is situated on a bend of the Clinch River at the upper end of the Watt's Bar Dam reservoir. The S-50 site, adjacent to the Power House, is in the extreme western part of the Clinton Engineer Works (App. A1, A2, B7), and is owned by the United States Government.

c. Objections Registered. - The Carbide and Carbon Chemicals Corporation, when informed of the proposed S-50 site, voiced concern over two points. The first point was the possible danger of explosion originating in S-50 because of the high pressures involved in the S-50 process; however, it was decided that, in view of the economics involved in construction and operation, location adjacent to the Power House was desirable (App. B2). The second point was the possibility of Power House condensate being contaminated by S-50 process material, thereby causing boiler corrosion, excessive scale, embrittlement, etc. Concern over this danger was minimized by the proposed use of conductivity meters and other safety

devices.

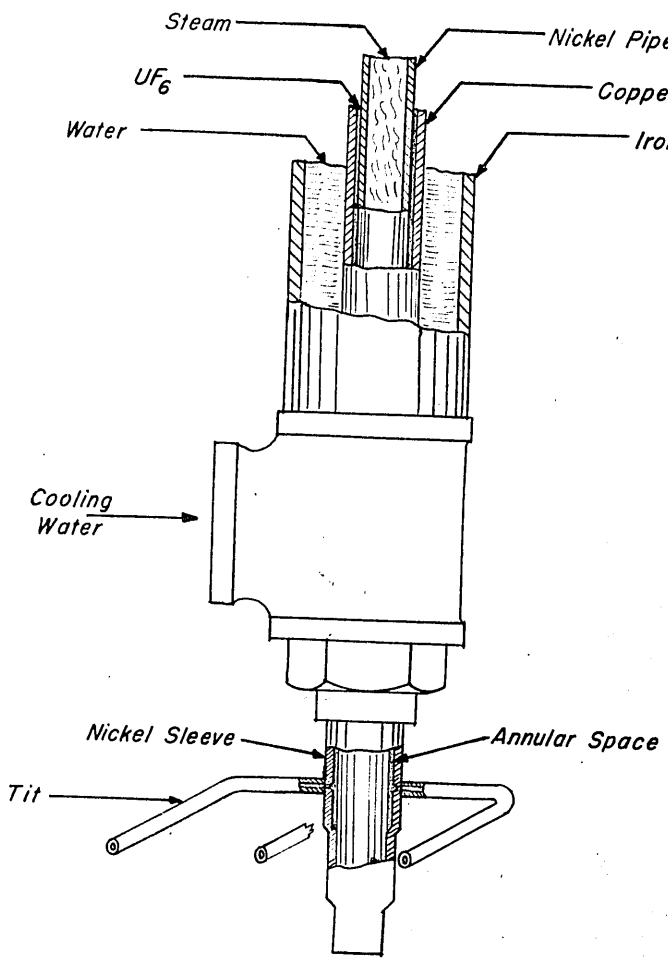
3-4. H. K. Ferguson Company Design. - Navy drawings which detailed column and rack construction for a contemplated naval production plant (App. G19 and G20) were turned over to the H. K. Ferguson Company on 26 June 1944, by order of Admiral King (App. D1), and work was immediately begun on the design of the plant according to instructions. The H. K. Ferguson Company engineers visited the Naval Research Laboratory and made the necessary engineering sketches, etc., for the complete design of a commercial rack installation. There were no fundamental changes made in the naval rack design; but, rather, the necessary auxiliary equipment was designed to adapt the power supply and other facilities at the S-50 site to this design. The H. K. Ferguson Company design included high-pressure steam lines and equipment, cooling water piping and equipment, and plans for the installation of the other utilities and buildings. The Main Process Building was designed and constructed simultaneously because of the short schedule allowed (Par. 3-8). In fact, a large part of the construction was executed from field sketches, detail drawings later being made from these sketches at the H. K. Ferguson Company engineering offices in Cleveland, Ohio.

3-5. Process Equipment Design.

a. Problems in Column Manufacture. - The Naval Research Laboratory had designed and constructed "tailor-made" columns. It remained for the H. K. Ferguson Company to put the technique of column manufacture on a commercial basis. In all, representatives of twenty-three manufacturers were consulted, none of whom considered that his company could accomplish the job as specified, until finally the Mehring

& Hanson Company (App. G14 and App. C30) and the Grinnell Corporation (App. C25) agreed to attempt the fabrication. The nickel tubing of the column had to be maintained to a tolerance of plus or minus 0.0003 of an inch in outside diameter and roundness all along the length of the tube. The clearance between this inner nickel cylinder and the outer copper cylinder had to be maintained to a tolerance of plus or minus 0.002 inches. This was indeed precision work, particularly since the total length of the column was about 48 feet, and it was not possible to draw copper or nickel tubing to these lengths. The nickel tube, therefore, was made by welding 24-foot lengths and even shorter pieces together, and the copper tube was made by joining lengths with silver-soldered sleeves. The dimension of the annular space between the inner nickel cylinder and the outer copper cylinder, a very critical dimension, was maintained by small nickel buttons, which were spot welded to the inner nickel pipe and acted as spacers. After proper selection of tubes had been made, and all other fabricating details had been accomplished, it was necessary to expand the nickel with steam heat so that the 48-foot nickel tube was about 5/8 of an inch longer than it would be at room temperatures. With the nickel in this expanded condition, it then had to be fastened to the copper, the copper meanwhile being held in a relaxed condition. In this way excessive stresses were prevented in the tubes, due to relative expansion during the later operation of the column when high-pressure steam passed through the nickel tube and cooling water passed along the outer surface of the copper tube. The copper cylinder was fastened to the central nickel cylinder by first silver-soldering a nickel sleeve as an extension on to the end of the copper tube, and then telescoping and welding the nickel sleeve over

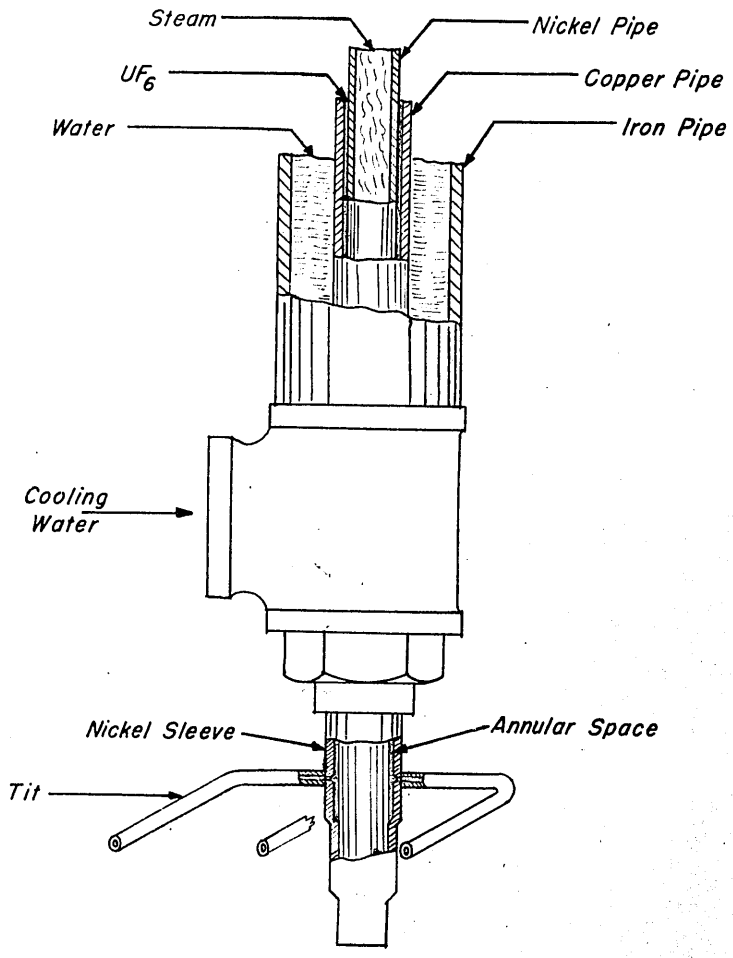
LIQUID THERMAL DIFFUSION (S-50) PROJECT



COLUMN SECTIONAL VIEW

Fig. 2

LIQUID THERMAL DIFFUSION (S-50) PROJECT



COLUMN SECTIONAL VIEW

Fig. 2

the nickel tube. This arrangement permitted the use of the more economical and procurable copper for the cold wall of the column. The nickel "tits" (see Fig. 2 and Par. 4-2a) could then be welded to the nickel sleeve, whereas it was impracticable to weld them to copper. The use of copper at the extremities of the cold wall tube was also precluded by the factor of corrosion by process material, which would be severe at these points, since they extend beyond the limit of the four inch water jacket, and were therefore at high temperature. One particularly distressing failure occurred occasionally because of a very small amount of sulphur in the acetylene used in the welding operations. The nickel tended to absorb the sulphur and became embrittled. Under the various stresses imposed on the metal, this nickel would then crack, causing complete failure of the column. Excellent analytical work on the part of the National Bureau of Standards exposed the presence of the sulphur and the situation was corrected. After repeated failures of similar nature, the Mehring & Hanson Company and the Grinnell Corporation worked out production methods which permitted each company to make as many as fifty columns a day. In planning the number of process columns to be grouped together in a structural unit or rack, it was considered convenient to choose 102, which is divisible by six. For operating purposes of supplying feed to, and withdrawing product from the columns, subdivision of the rack into six banks or circuits containing 17 columns each was contemplated. Later in actual operation, many of the racks were divided into four circuits of 25 or 26 columns each. The installation of 21 racks of 102 columns thus called for a total of 2142 installed process columns.

b. Material Feed and Withdrawal Equipment. - The Naval

Research Laboratory had furnished the fundamental design of the essential elements of the material feed and withdrawal system, such as the convection loop (Par. 4-2d), the required volume and operating conditions for the material reservoir, the size of the necessary tubing, and the material circuit as a whole. The H. K. Ferguson Company designed the reservoir (Par. 4-2c) and auxiliary equipment, and the arrangement of that equipment in the transfer room and control room (Par. 4-2e). An example of this was the design of an armor-plate barricade surrounding the reservoir and obviating explosion dangers due to possible excessive pressures developing in the reservoir. Essentially, the material feed design called for a closed circuit of nickel tubing from the reservoir through the bottoms of the columns, through the pumping convection loop, and back to the reservoir (Fig. 5 facing p. 5.5).

3-6. Process Steam System.

a. Introduction. - At the time of the construction of the S-50 Plant, the need for S-50 product was so great that the plant was designed to take advantage of the maximum amount of energy that the K-25 Power House could deliver, in order to gain all possible operating time. It was realized at the time of this design that the K-25 Power House would be able to furnish its maximum output only part of the time because of scheduled and emergency maintenance outages and other reasons. From the outset, lack of sufficient steam from the K-25 Power House was an important factor limiting plant production (Par. 5-6a). After several months of S-50 operations, increasing K-25 power needs indicated that an even more serious steam shortage impended. Plans were therefore drawn up for a New Boiler Plant in the S-50 Area. The New Boiler Plant was designed to supply steam

to one of the three sections (Par. 4-2b) of the S-50 Plant, and the K-25 Power House was thereafter called upon to supply only two sections.

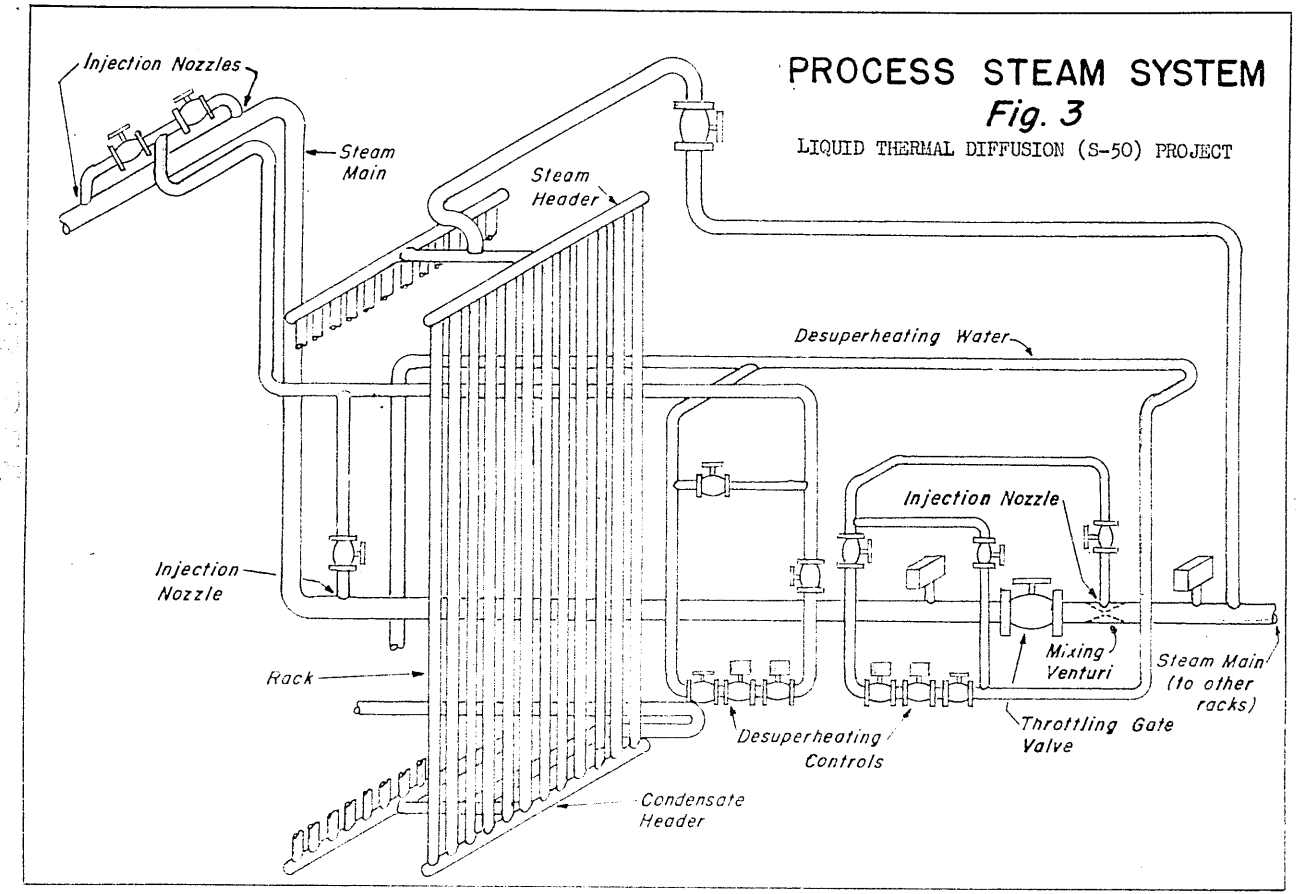
b. Steam Supply from the K-25 Power House.

(1) Desuperheating and Pressure Reduction. - The K-25 Power House supplied superheated steam at 1250 p.s.i. and 925°F for the S-50 process. However, the Naval Research Laboratory specifications (Par. 2-4c) required saturated steam, at 1000 p.s.i. and 545°F. It was, therefore, necessary not only to reduce the pressure of the K-25 Power House steam, but also to remove a large quantity of superheat, the elimination of which presented an unusual design problem. The superheat was absorbed by relatively cool water, which was injected into the steam mains and flashed into steam. The desuperheating operation called for the design of special pumps (Par. 4-3a) capable of handling water at the high saturation temperatures. The Pacific Pump Company successfully designed, built, and delivered these unique pumps in an amazingly short time. In operation, the desuperheater pumps took some of the water from the rack condensate return lines and injected it into the steam mains through four individual nozzles (per main) spaced about 50 feet apart. Thus, desuperheating was performed in stages to eliminate excessive stress in the lines from drastic cooling. To reduce the pressure of the steam to the required 1000 p.s.i., a hand-operated gate valve was installed downstream from the desuperheater nozzles in each main. In order to insure thorough mixing of the desuperheated steam with the steam which was generated from the desuperheating water, a mixing Venturi (Par. 4-3b) was provided in each main immediately after the pressure-reduction valves. The injection of the desuperheating water resulted in a 40 per cent increase in the 1000 p.s.i. steam rate; i.e., where

PROCESS STEAM SYSTEM

Fig. 3

LIQUID THERMAL DIFFUSION (S-50) PROJECT



the process required 112,200 pounds per hour of 1000 p.s.i. steam for each rack, the K-25 Power House was called upon to supply only 80,100 pounds per hour of 1250 p.s.i. steam. The steam supply system can be visualized with the aid of Figure 3.

(2) Delivery and Condensate System. - Three mains were connected into the steam header in the turbine room of the K-25 Power House. (One main was later switched to the New Boiler Plant header- see Par. 3-6c.) These mains were the process steam supply lines, each one serving a seven-rack section. Steam was tapped from a main and conducted to steam headers above the seven racks in the section served by the particular main. These manifolds supplied steam to the vertical columns where condensation took place. Condensate level was held at a constant height below the annular spaces by means of a control valve on the condensate return header below each rack. This arrangement prevented excessive steam flow through the column (with corresponding drop in pressure), prevented the condensate from filling the column, and prevented steam from entering the condensate lines. Difficulties arose in the handling of the condensate returned to the K-25 Power House, because the condensate was practically at saturation conditions, and any expansion, through valves, heat exchangers or other equipment, caused dangerous flashing. The Power House operators recognized these dangers and executed corrective measures which included the construction of a 100,000-gallon condensate storage tank, heat exchangers, additional back pressure valves, etc.

(3) Auxiliary Facilities. - The system as a whole was provided with drainage facilities. In addition, a blowdown system was installed primarily for the purpose of maintaining proper condensate level in the columns. It was used principally when starting up or shutting down

a rack. Blowdown condensate was collected in a blowdown tank from which as much of the condensate as possible was returned to the K-25 boilers by way of the S-50 low pressure condensate system.

c. Steam System of New S-50 Boiler Plant.

(1) Change in Steam Specifications. - In January 1945 it was proposed that the Naval Research Laboratory steam specifications (Par. 2-4c) be compromised in order that lower pressure surplus Navy boilers (Par. 4-4a) might be utilized in augmenting the steam supply from the K-25 Power House. It was contended that while the productivity of the process equipment would drop, there would be a reduction in operating difficulties (Par. 5-6a) and the ultimate mean daily production would approach the figure reached when operating with 1000 p.s.i. steam (App. D4). Production resulting from operations with the proposed boilers actually proved very satisfactory (App. G26). The design of the New Boiler Plant, therefore, centered around the utilization of available surplus Navy equipment and the adaptation of that equipment to conform as closely as possible to the particular requirements of the S-50 Plant.

(2) Boiler System. - The design of the New Boiler Plant, as worked out by the H. K. Ferguson Company, called for a plant of twelve boilers capable of furnishing 630,000 pounds per hour of saturated steam at 450 p.s.i. The original boilers were constructed to supply 750°F superheated steam and were equipped with economizers. Since saturated steam was required for the S-50 process, it was necessary to remove both the superheaters and the economizers from the boilers. This resulted in a stack temperature of around 800°F, causing very inefficient boiler plant operation. Therefore, the Babcock & Wilcox Company (App. C18), consultants for the installation, suggested that air heaters be installed in the boiler

stacks to recover a large amount of the heat. This was done, with a resulting stack temperature of around 500°F. In order to control the firing of all twelve boilers adequately, it was decided to install one control panel (Par. 4-4a) that was entirely automatic and would equally distribute the load among the twelve boilers. The plant was built to operate as a closed system; and by removing only the latent heat from the steam, the over-all pressure drop and temperature drop were about 50 p.s.i. and 50°F respectively. The boiler feed pumps (Par. 4-4a) which were utilized had been designed to deliver at 250 p.s.i. pressure, but were adapted to deliver at 650 p.s.i. Two additional pumps, capable of delivering at 525 p.s.i., were provided to supply make-up water, to replace that lost in the closed system because of leaks, etc. Each boiler was equipped with a turbo-driven forced draft blower, and the exhaust steam from this auxiliary equipment was condensed and recycled as boiler feed water. The delivery system in the one section of the Main Process Plant to be served by the New Boiler Plant required no essential changes, as the 450 p.s.i. steam could be handled more safely than the previously used 1000 p.s.i. steam.

(3) Tank Farm - Because of the fact that the fuel oil situation on the East Coast was critical, the Petroleum Administrator for War, and the Office of Defense Transportation advised that ample oil storage be provided in the event of an emergency during the coming winter. Their suggestion, that a minimum 60-day supply of oil be stored, established the design criteria for the approximately 6,000,000 gallons of storage provided at the S-50 site. This large oil storage system amounted to a major tank farm installation (App. B8), which was not originally contem-

plated, and resulted in a considerable increase in the cost of the New Boiler Plant construction. The H. K. Ferguson Company was called on to design the Tank Farm around surplus equipment available in Army stock. The final design of the Tank Farm incorporated the use of thirteen tanks, with two pump houses for unloading tank cars, and transferring oil to the New Boiler Plant service tanks. A small auxiliary Boiler Plant No. 2, utilizing four Kewanee boilers, also obtained from surplus Army stocks, was intended for heating the oil during cold seasons.

3-7. Cooling Water System. - The water necessary to maintain the outer copper wall of the annular space at low temperature was pumped through the column jackets by means of a cooling water pump (Par. 4-5a) which supplied a manifold running horizontally through the bottom of the rack and feeding the individual columns. A similar manifold collected the water leaving the tops of the columns and returned it to the pump, which thus maintained a steady circulation. Actually this return water flowed through a suction header serving four circulating pumps: one in operation, one in stand-by, and two more for the adjacent rack. The single pump header serving two racks provided for greater flexibility of interchanging pumps. However, in normal operation the water circulating systems for the two racks were kept entirely separate by means of a "sectionalizing valve." Cooling water entered the columns at 150°F and was heated to 160°F in passing through the rack. In order to maintain the re-entering water at 150°F, a "make-up water" line was connected into the pipe returning column discharge water to the pump. The rate of flow of the make-up water was controlled by an automatic temperature regulating valve actuated by a thermometer located in the lower manifold leading to the columns. Four

make-up water pumps (Par. 4-5b) were available for moving water from the pump well through a large underground header on the west side of the building, from which the make-up water lines to the individual racks were tapped. The pump well in turn was supplied with Clinch River water pumped from the K-25 Power House (Book II, Vol. 5). A quantity of water, equivalent to the make-up water fed into the circulating system, was continuously removed by an overflow line from the top rack manifold to a final underground waste header on the east side of the building. One particularly troublesome problem in the design of the cooling water system was that of providing for the relative expansion between the cooling water header and the columns. The Philadelphia Pilot Plant had used expansion joints of the stuffing box type, but the use of this joint at each column in the full scale production plant would constitute a potential construction bottle-neck. In order to save considerable time and also for the sake of economy, the B. F. Goodrich Company (App. C24) was asked to design rubber hose for the application. This was accomplished, and in this manner, the stuffing box type of joint was eliminated.

3-8. Construction Schedules.

a. Main Process Plant. - At the outset (June 1944), it appeared to qualified observers that a period of six months would be an optimistic schedule for the construction of the S-50 Plant, but in view of the importance attached to the project a four-months schedule was discussed. The desire to have the process in operation became so great that even this schedule was cut to seventy-five days, in so far as the actual start of operations was concerned (App. D2). One of the most important considerations was the need for placing one unit into operation as quickly as possi-

ble for training purposes. Although the Naval Research Laboratory had had some experience in operating a low-pressure plant at Anacostia, and although one unit using 1000 p.s.i. steam was under construction at the Philadelphia Navy Yard, no experience had been gained in the actual operation of a plant using 1000 p.s.i. steam. Despite the handicap of operating one unit in the midst of the construction work, it was absolutely necessary that operating personnel be trained at the earliest possible moment. The other objective, of course, was to get the entire plant into production as soon as possible. It was finally directed that initial operation be started on 16 September 1944 and that all construction be completed within forty-five days thereafter. Despite the fact that the H. K. Ferguson Company considered this an impossible schedule they exhibited an indomitable will to try to meet it. Preliminary operations were actually started on 16 September (sixty-nine days after construction began), but it soon became evident that the remaining plant construction schedule could not possibly be met because of delays such as those which occurred in the fabrication of the process columns. Although the construction graph (App. A8) indicates that the contractor was behind schedule for the remainder of the job period, it should be remembered that the extremely stiff schedule was set up deliberately for obvious psychological reasons.

b. New Boiler Plant. - The auxiliary New Boiler Plant was likewise built under pressing conditions; and at the time when the construction was started (March 1945), it was hoped that the New Boiler Plant would be ready for operation by as early as 1 June 1945 (App. G29). However, the start-up deadline was moved back to 1 July (App. G30) because of the late delivery of pumping equipment and other delaying factors. Through

the efforts and improvisations of the contractors, preliminary operation did begin the first week of July, and the New Boiler Plant was on the line in a steady operation condition by 13 July. The early estimates (April 1945) called for the overall completion of the New Boiler Plant and its auxiliary equipment by 1 September (App. G31); all the work actually was complete by 15 August, with the exception of a few minor installations and some insulation work.

3-9. Procurement.

a. Main Process Plant. - The instructions to the H. K. Ferguson Company regarding the construction of the S-50 Plant were to build an exact duplicate of the Philadelphia Pilot Plant. This was possible with regard to the process, but impossible in the construction and installation of the necessary utilities. These instructions were precisely followed in the immediate purchase of a great many items, but many others, such as high pressure steam equipment (Par. 4-3), required special designs and modifications for adaptation to commercial scale. Furthermore, certain items were not available in the limited time allocated to the job, and substitutions were necessary. On all items immediately purchasable, the H. K. Ferguson Company was instructed to place immediate telephone or telegraph orders without competition, using vendors which had supplied the Naval Research Laboratory where possible. The Washington Liaison Office of the Manhattan District did exceptional work in the establishment of the high priorities which were issued to the vendors. High pressure expediting was executed by officers attached to the S-50 Project who were located in industrial centers throughout the country.

b. New Boiler Plant. - Practically the only pieces of

equipment required for the New Boiler Plant, other than those furnished from the Navy and Army surpluses, were the boiler feed pumps (Par. 4-4a), the fuel oil pumps (Par. 4-4b), and the oil heaters for the fuel system. The H. K. Ferguson Company handled the procurement of this equipment.

3-10. Construction Chronology.

a. Main Process Plant and Auxiliary Buildings. - On 5 July 1944 the H. K. Ferguson Company placed an order with the Mehring and Hanson Company for the manufacture of process columns, and on 9 July the clearing of the site began. By 1 August most of the structural foundations for the Main Process Building were complete. On 17 August the installation of process equipment was begun. The first process columns were received from the Grinnell Company (App. C25) on 27 August. By 16 September, the date scheduled for the beginning of operations, one third of the Process Building was complete, and 320 columns were on hand. The Fercleve Corporation (Par. 5-2), as operating contractor, had begun conditioning of Rack No. 21. One of the three main steam lines from the Power House was heated up on this date, and cooling water circulation was begun on Rack No. 21. It was desired to complete the remainder of the plant by 15 October, but delays in fabrication and shipment of columns made this impossible. Late in October, by which time experience with the operating racks had shown considerable leakage of high pressure steam at the screwed unions at top and bottom of the columns, the decision was made to replace all unions with welded connections. This was done, and involved the use of a large amount of welding labor. By 15 January 1945 all construction of the 21 racks was complete except for a few small piping changes which were found necessary on the basis of experience with the

racks operated thus far. In order to close out the main contract properly, a stop order was issued to the H. K. Ferguson Company as of 15 February 1945, at which time all originally contemplated work had been completed with the exception of some insulation work and some additions to the electrical system. The two subcontracts covering these items were assigned to the Government and finished by 15 March 1945 (App. C6, C13). The auxiliary buildings (App. E1) were completed by 4 February. Certain services, such as the furnishing of ready-mixed concrete, the laying of the domestic water supply line for the plant, and the clearing of the site were rendered by the J. A. Jones Construction Company, Inc. (App. C2), which was under contract for other construction work in the K-25 Power House Area (Book II, Vol. 4). Some electrical work, such as the splicing of cables, was done at the request of the H. K. Ferguson Company by the Schulman Electric Company (App. C4), also employed on contracts in the Clinton Engineer Works. The auxiliary switch house for furnishing electric power to the S-50 Project was designed by the Kellex Corporation (App. C19) and was constructed by the Jones and Schulman organizations. (A chronological series of pictures of the construction of Main Process Plant may be found in Appendix B1 through B5.)

b. New Boiler Plant. - The construction of the New Boiler Plant was approved by the District Engineer on 16 February 1945 (App. G27). The J. A. Jones Construction Company received drawings from the H. K. Ferguson Company, and on 16 March started stripping the site of foundations. Twelve new and partially assembled Destroyer Escort boilers, arrived on 26 April, furnished by the Navy from surplus stock at a plant of the Consolidated Ship Building Company, Inc., at Orange, Texas. Through

the efforts of the Washington Liason Office a number of excess 25,000 and 482,000 gallon tanks were shipped from surplus Army stock. The Grinnell Company, Inc., (App. C5) erected and tested all high pressure steam, condensate, and fuel oil piping for the Boiler Plant. The Wm. A. Pope Company (App. C3) installed the oil unloading and distribution lines in the Tank Farm. The first carload of oil was unloaded on 30 May. Preliminary operation was begun on 5 July when steam was obtained from the first of the twelve boilers. On 13 July the Boiler Plant went on the line in a steady operating condition. With the exception of the installation of a few instruments, a small amount of insulation, and some painting, all work on both Boiler House and Tank Farm was complete by 15 August.

3-11. Labor Procurement. - Probably the most difficult phase of the S-50 construction encountered by the H. K. Ferguson Company was the procurement of the necessary labor to complete the project within the stipulated time. For two years the labor market in the region surrounding the S-50 site had been classed as extremely critical. The H. K. Ferguson Company brought in their top supervisory personnel. Fortunately, the Project Manager kept a card index of various mechanics and craftsmen that had worked for him on other projects around the country. He immediately sent application blanks to these people, and in this manner he was able to effect transfers of large numbers of skilled personnel to the project without violating any War Manpower Commission regulations. Two of the main subcontractors, the Edenfield Electric Company and the Turner and Ross Construction Company, were likewise able to bring in personnel from other jobs they were completing at the time the S-50 contracts were awarded. Local union business agents cooperated in procurement of personnel, but

most of the higher quality craftsmen and laborers from the surrounding localities were already employed on other Clinton Engineer Works projects. The H. K. Ferguson Company maintained a staff of four labor recruiters who worked with the U. S. Employment Service in sections not classed as critical labor areas. Throughout the entire course of the job the labor requirements were never fully met, especially in the unskilled grades, although the long hours worked on the job provided an incentive to work here. A graph showing numbers of non-manual employees, laborers and tenders, and craftsmen, may be found in Appendix A9. Rates of wages may be found in Appendix E2.

3-12. Security. - Since the S-50 site was located within the K-25 Area, the enforcement of security regulations was not a difficult matter. Security was under the supervision of the H. K. Ferguson Company security agent who maintained close liaison with the District Intelligence Officer. With the exception of two or three minor cases of theft, no serious security problems were encountered during the entire course of the project. Orientation of personnel to security regulations and procedures was accomplished in accordance with standard District methods as described in Book I, Volume 14.

3-13. Safety. - One of the first units organized at the S-50 site was an adequate safety division headed by a safety engineer with four or five assistants. Because of the speed of the project, the work was fairly hazardous. No normal course of operation could be followed, as it was necessary, for example, to erect structural steel over other operations within the same areas. In spite of these difficult construction conditions, the S-50 organization maintained one of the best safety

records in the entire Clinton Engineer Works. This is to be attributed largely to the effectiveness of the safety campaign carried on continuously by safety department personnel. Injury rates of S-50 construction companies and the Clinton Engineer Works as a whole may be found in Appendix D8.

3-14. Summary of Design and Construction Costs. - The total overall S-50 design and construction cost, as of 1 June 1946, was estimated by the District Cost Section to be $12,910,639. The portion of this total applying to work in the S-50 Area proper, and the portions applying to work in the K-25 Area necessitated by the S-50 Project, are listed in Appendix D6.

SECTION 4 - DESCRIPTION OF PLANT

4-1. Buildings. - All buildings in the S-50 Area were auxiliary to the Main Process Building, wherein the separation of uranium isotopes was effected. The Main Process Building (App. B6,B7) was 522 feet long by 82 feet wide by 75 feet high, with concrete foundation, structural steel frame, sides and roof of Robertson Protected Metal, and a concrete floor. A mezzanine ran the full length of the west side of the building, on the first level above the main floor, and was partitioned into eleven transfer rooms and eleven control rooms. The Main Process Building housed the process equipment, consisting of twenty-one racks and the appurtenant steam and cooling water equipment. For each two racks there was a transfer room which contained the equipment utilized in the transfer of material into and out of the reservoirs and racks. There was also one control room adjoining the transfer room for each pair of racks. This room contained most of the process control instruments and was used as a headquarters and office for the operating crew of the two racks. The twenty-first rack with its transfer and control rooms served as an experimental unit, while the rest of the plant was used for regular production. Two elevators, one at either end of the building, operated between the floor and the catwalks at the tops of the racks. (For a floor plan of the Main Process Building showing arrangement of equipment, etc., see App. A6). Auxiliary buildings included three pump houses, a water treatment plant, two laboratory buildings, a change house, an administration building, a machine shop, warehouses, a cafeteria, a time office and clock alley, a first aid building, a gasoline filling station, a storage shed, a canteen,

two boiler plants, a conditioning shop, and a switch house (App. E1).

4-2. Process Equipment.

a. Column. - The basic element of the S-50 plant was the column in which the actual isotope separation was effected. There were 2142 identical 48-foot process columns, each consisting of three concentric tubes: the innermost made of 1¼ inch nickel pipe, the middle one made of slightly larger copper pipe, and the outermost made of four inch galvanized iron pipe. The radial dimension of the annular space between the nickel and copper pipes, which contained the process material, was maintained by severe tolerance specifications at 0.010 inch plus or minus 0.002 inches (0.250 mm. plus or minus 0.050 mm.). Steam at 1000 p.s.i. and 545°F passed downward through the nickel pipe, and water at an average temperature of 155°F passed upward through the outer iron jacket. The necessary temperature differential of approximately 390°F was thereby maintained across the annular space. At the top and bottom of the column were three small projecting nickel tubes or "tits" (Fig. 2 facing p. 3.6) which connected with the annular space and were used for the addition or removal of process material.

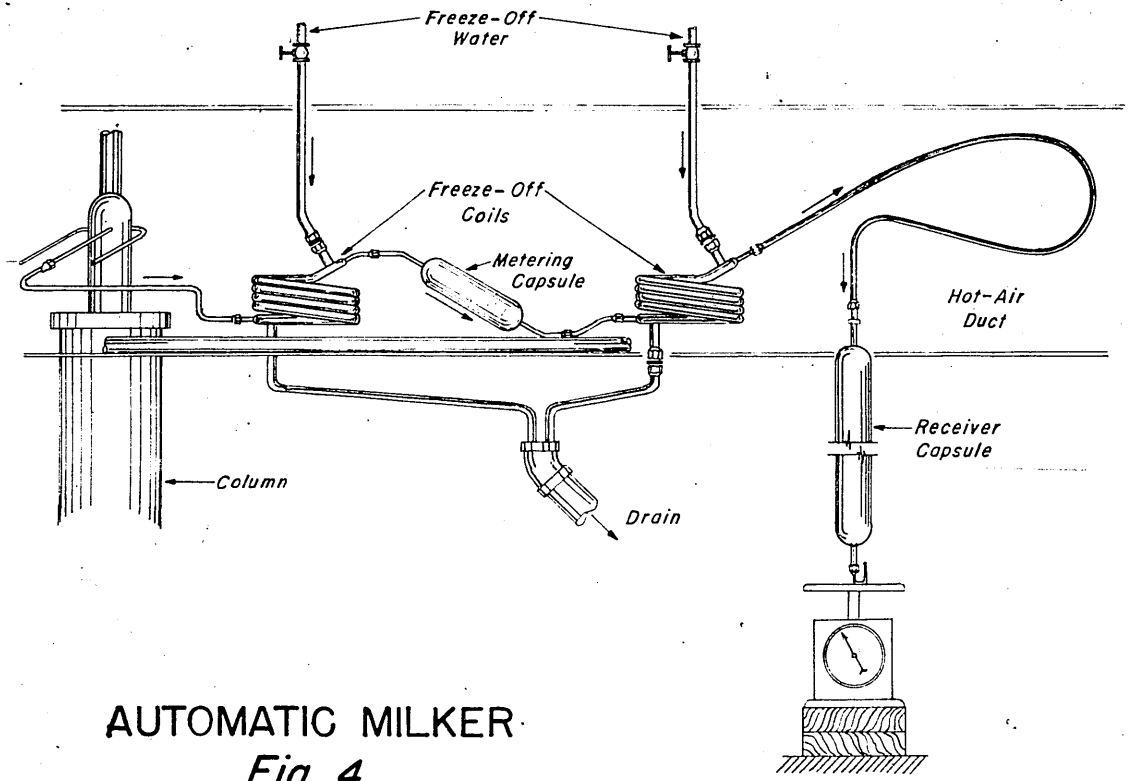
b. Rack Equipment. - Columns were installed in groups of 102, each of which was supported by a structural steel framework and arranged in two rows of 51 columns each. The framework and columns, together with accessory steam, air, and water lines, valves, pumps, gauges, etc., comprised the operating unit at S-50 known as a "rack" (App. B10,B11). The racks in the S-50 plant were divided into three groups of seven which were designated as "sections". The three sections were identical in operation, and were arranged in this manner merely to simplify the distri-

bution of steam to the racks, each section being served by a single steam main. For operational purposes, the columns of a rack were divided into 2, 4, or 6 groups called "circuits". The material channels of the columns in each circuit were connected in parallel, and each group acted as a separate unit for feed and product removal. The columns were connected at the top and bottom by "intercolumn connectors" which were short nickel lines equipped with female Lunkenheimer fittings so that they could be attached to the male nickel tits projecting from the ends of the columns. Copper tubing was brazed to the nickel material lines, through which water could be passed, when desired, for freezing off the connections between the columns by causing a solid plug of frozen process material to form and block the line. (A 24 inch header running the length of the process building near the roof supplied water from the water treatment plant for the freeze-off system.) When the flow of freeze-off water through the copper tubing of the intercolumn connectors was shut off, the heat of the duct*, in which these connections were enclosed, caused the solid plug of process material to melt, thus allowing the material to flow again. For indicating direction and relative rate of material flow, a "Hoffman flow-meter" was installed between two adjacent columns of each circuit inside the rack duct. The flowmeter was made up of two thermometers, spaced about 12 inches apart, attached to a nickel line. The thermometers showed a difference in temperature when the process fluid was flowing thru the nickel line because of heat loss in the relatively cool duct, but both thermometers quickly dropped to duct temperature when the circulation stopped. Terminal boxes at various points in the lower rack duct, contained the ends of the conduit lines through which the material flowed between the reservoir and rack. Copper-

jacketed nickel coils were used to freeze the material in the nickel lines between the conduits and the rack in case of a break in the material circuit, so that both the reservoir and the rack would not be emptied.

c. Reservoir. - The reservoir was an 8 inch by 8 foot nickel cylinder with a half inch wall. It was equipped with an internal nickel steam coil and an outer steel jacket for low pressure steam or water. Each reservoir was mounted on scales so that the amount of material inside would be known at all times, and each bank of reservoirs was surrounded by a protective armor-plate barricade. Six reservoirs were located in each transfer room, and were used to store process material for the rack circuits, and to control the operating material pressure by varying the pressure of the steam to the inner coil. Three reservoirs were available for each of the two racks served by the room. (In plant parlance the reservoirs were commonly called "storage tanks", "storage chambers", and "scale tanks".)

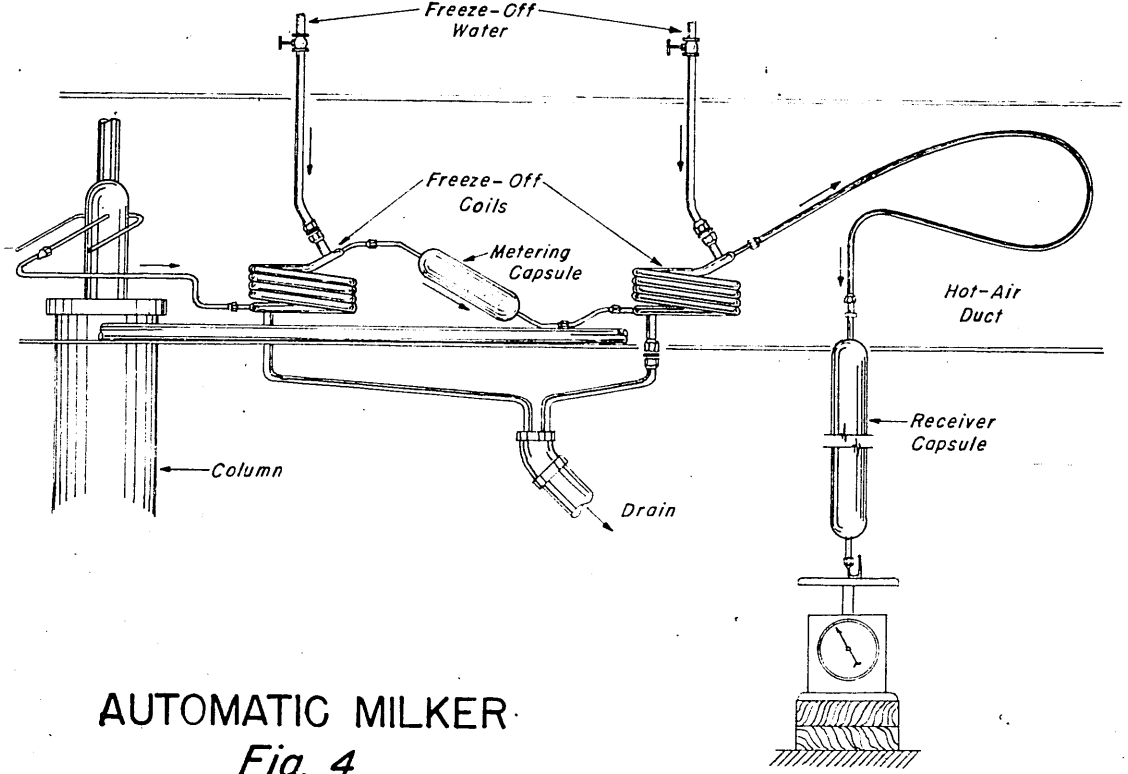
d. Convection Loop. - The convection loop utilized the phenomenon of convection to supply a motivating force for circulation of process material. Convection was particularly effective with UF_6 because of its extremely large rate of change of density with respect to temperature. The convection loop actually consisted to two nickel tubes which were linked together in the shape of a 48-foot high, inverted "U"; one of the legs was warmed by a 5 p.s.i. steam jacket and the other was held at higher temperature by means of a 150 p.s.i. steam jacket. Since the density was greater in the cooler leg, the process fluid tended to fall on that side and to rise on the hotter side, thereby providing the pumping action necessary for movement of process fluid through the circuit. The material system was under a pressure of 1500 p.s.i., but the total differ-



AUTOMATIC MILKER

Fig. 4

LIQUID THERMAL DIFFUSION (S-50) PROJECT



AUTOMATIC MILKER

Fig. 4

LIQUID THERMAL DIFFUSION (S-50) PROJECT

ential in pressure of three or four p.s.i., which was caused by the convection loop, maintained the flow (see Fig. 1,facing p. 2.13).

e. Control Room Equipment. - A large panel in the control room indicated the pressure of the process steam and convector steam, the temperature of the cooling water, the pressure and rate of flow of the make-up water, and the suction and discharge pressure of the cooling water pumps. A recording potentiometer indicated the state of material flow by giving temperature readings from thermocouples which were conjoined with Hoffman flow-meters in the rack circuits. Electrical controls were provided for carrying out the milking operation by remote control, for freezing off rack circuits when desired, and for operating exhaust fans which were used to sweep the rack or transfer room ducts clear of process fumes when necessary. An annunciator system sounded a warning horn when certain process variables approached a dangerous or undesirable point. For example the buzzer would sound in the event of unduly high cooling water temperature, or failure of process steam, electric power, or freeze-off water supply.

f. Milker. - The purpose of the automatic milker (Fig. 4) was to remove product mechanically from a plurality of columns. In order to withdraw product from all the columns of a circuit simultaneously, the tops of the columns were normally connected in a series (or "monorail") by means of intercolumn connectors. The milking apparatus consisted mainly of two water-jacketed freeze-off coils* (utilizing the novel valving action described in Par. 5-5a), a metering capsule, and a receiver capsule mounted on a scale. By alternately unfreezing the coils (by turning off the water flowing through the jackets, sweeping the jackets

clear with compressed air, and thus allowing the heat of the duct to melt the UF_6), the columns were milked periodically in small, equal increments.

g. Assay Laboratories Equipment. - Two assay laboratories (Par. 5-5c) utilized mass-spectrometers* and alpha-counters* in control work.

4-3. 1000 p.s.i. Process Steam Equipment.

a. Desuperheating Water Pumps. - The installation required three 4-inch, three-stage, centrifugal hot water pumps, manufactured by Pacific Pumps, Inc., (App. C32) and designed to handle 900 gallons of water per minute at 535°F, with a suction pressure of 950 p.s.i. and a discharge pressure of 1400 p.s.i.

b. Venturi Type Desuperheating Elements. - To facilitate complete mixing and uniform temperature in the desuperheated steam, three 10-inch x 12-inch 1500 p.s.i. standard carbon molybdenum steel Venturis were installed, one in each of the three main steam lines. These elements were supplied by the Swartwout Company (App. C36).

c. Throttling Valves. - The throttling of the desuperheated steam down to 1000 p.s.i. was accomplished by means of three 10-inch worm-gear-operated valves supplied by the Chapman Valve Manufacturing Company (App. C22). These were cast steel gate valves with carbon molybdenum steel seat rings and discs.

d. High Pressure Piping. - Steam at 1250 p.s.i. and at a temperature of 925°F (353°F of superheat) was conducted through 10-inch schedule 160 molybdenum steel pipe. Saturated steam at 1000 p.s.i. and 545°F was carried through 6-, 8-, and 12-inch carbon steel pipe. Con-

densate at 950 p.s.i. and at 535°F was handled in 4-inch schedule 160 carbon steel pipe (Fig. 3 facing p. 3.11).

4-4. New Boiler Plant.

a. Boiler House Equipment.

(1) Boilers. - The new steam generating plant utilized twelve Destroyer Escort type boilers (App. B9), which had been manufactured by the Babcock and Wilcox Company, and which were obtained from surplus Navy stock. These boilers were altered from their original design, to supply steam as required by the process. The removal of superheating elements and economizers gave these boilers a rating of approximately 53,000 pounds per hour of saturated steam at 450 p.s.i. The total New Boiler Plant output was thus approximately 630,000 pounds of steam per hour.

(2) Boiler Feed Pumps. - Three 4-inch, single stage, double suction Pacific centrifugal pumps were used to supply the boilers with feed. These pumps delivered 700 gallons per minute of 400°F water at a discharge pressure of 550 to 650 p.s.i., when operating at a suction pressure of 350 to 450 p.s.i. Two pumps were motor driven and one was turbine driven.

(3) Make-up Pumps. - Two 3-inch, four stage Pacific centrifugal pumps served as make-up pumps. The pumps delivered 300 gallons per minute at a discharge pressure of 525 p.s.i. Suction pressure was atmospheric.

(4) Forced Draft Fans. - Two boilers were equipped with Westinghouse (App. C37) turbo-driven blowers and ten were equipped with Sturtevant (App. C35) turbo-driven blowers. The respective ratings

were as follows: Westinghouse, 24-inch, 24,000 cubic feet per minute, at 5,650 revolutions per minute and a static pressure of 26 inches; Sturtevant, 24-inch, 24,000 cubic feet per minute, at 3,525 revolutions per minute and a static pressure of 26 inches.

(5) Condensers. - Nine Struthers-Wells (App. C34) feedwater heaters were arranged to act as condensers. Shell pressure was 10 p.s.i., tube pressure was 575 p.s.i., operating temperature was 250°F. Two heaters were used for cooling surge tank overflow, three heaters were used for condensing gland leak-off from the boiler feed pumps, and four were used to condense auxiliary steam.

(6) Fuel System. - Six 25,000-gallon tanks, each equipped with steam heating coils, supplied the suction for three fuel oil pumps located inside the northwest corner of the plant. The discharge from the Worthington fuel oil pumps entered a six-pass Griscom-Russell (App. C26) oil heater, designed for maximum working temperature of 400°F. Working pressures were 250 p.s.i. for the shell and 300 p.s.i. for the tubes. From the oil heaters the fuel was piped to the individual Iowa type burners.

(7) Condensate System. - Two 25,000-gallon tanks supplied the make-up pumps. Since the Griscom-Russell evaporator was not originally in service, a three-inch line to these tanks was installed from the K-25 Power House evaporator reservoirs. These two tanks also received the condensate from the nine feedwater heaters.

(8) Miscellaneous. - Other boiler house equipment included several small condensate pumps, several small condensate receivers, an air compressor for the control system, etc.

(9) Piping. - All boilers fed into a common 12-inch header. The lead to the plant main was separated from the boiler header by a motor operated valve. A 10-inch line returned the condensate from the Main Process Building to three Struthers-Wells water heat exchangers where the return condensate was cooled to prevent flashing in the surge tanks. It was found unnecessary, however, to use the heat exchangers and later a by-pass was installed around them. From either the by-pass or the heat exchangers the condensate was piped into two surge tanks, which acted as a reservoir for the suction of the boiler feed pumps. The pressure in the surge tanks was kept constant at a predetermined value, by means of a steam cushion supplied from the main header through a regulating valve.

(10) Boiler Control System. - Full automatic boiler control was provided for by the installation of Bailey (App. C20) thermo-hydraulic feedwater controls and Bailey air-controlled fuel-air ratio controllers. Except for lighting and cleaning burners, the plant could be operated from the Bailey control panel located in the center of the plant.

b. Tank Farm Equipment.

(1) Oil Storage Tanks. - Thirteen tanks (App. B8), each 48 feet in diameter and 36 feet high, formed an oil storage reservoir of six million gallons capacity. Each tank was equipped with steam heating coils for pumping oil in cold weather. Foamite equipment was also installed, for use by the fire department. Suitable dykes were provided to retain the oil in case of tank failure.

(2) Pumping Equipment. - Two small pump houses each

containing four Worthington rotary oil pumps, rated at 400 to 500 gallons per minute, were provided for unloading and transferring oil.

(3) Boiler Plant No. 2. - Four Kewanee (App. C29) oil-fired boilers, originally designed for working pressures of 150 p.s.i., supplied 75 p.s.i. steam to the oil heating coils and tracer lines, to reduce the viscosity of the oil along the unloading, transfer, and supply lines. These boilers were housed in a concrete building 33 feet wide, 73 feet long and 25 feet high. The building also contained a boiler feed pump and condensate receiver.

(4) Miscellaneous Equipment. - The remainder of the equipment included: unloading piping capable of handling thirty cars simultaneously, transfer piping to the oil storage tanks, and supply piping to the boiler plant; 3500 feet of railroad track, fire hydrants, catwalks, etc.

4-5. Cooling Water Equipment.

a. Cooling-Water Pumps. - The circulating water for each rack was pumped through a recirculating system by a single-stage 16-inch cold water centrifugal pump, manufactured by the Pacific Pumps, Inc. These pumps were designed to handle 10,000 gallons per minute of water, at a suction pressure of 20 p.s.i. and a discharge pressure of 30 p.s.i.

b. Make-up Water Pumps. - Make-up water was supplied to the rack circulating water system by four 36-inch single-stage, centrifugal, turbine pumps, manufactured by the Pacific Pumps, Inc. These pumps were designed to deliver 15,000 gallons per minute against a 90 foot head.

4-6. Water Treatment Plant. - A 10-inch pipe, running from the discharge line of the cooling-water make-up pumps to the Water Treatment

Plant, supplied screened river water to the freeze-off water treating system. The Water Treatment Plant utilized Permutit Spaulding type filtering and treating equipment in processing continuously between 700 to 1000 gallons of water per minute. The necessary chemicals (i.e., lime, alum, clay, and chlorine) were added to the raw river water through 1-inch lines running to the inlet flumes on the filtering tanks.

4-7. Utilities.

a. Water Supply. - Potable water for the S-50 Area was supplied through a 10-inch line from the main water supply for the K-25 Area (Book II, Vol. 4). Elevation of the three 500,000-gallon tanks installed for the K-25 Area was 938.50 feet above sea level. Since the elevation at the Main Process Building was 750.50 feet above sea level, there was a difference in elevation of 188 feet, which created a pressure of about 90 p.s.i. in water mains in and around the building.

b. Sewage Disposal. - Sewage from the S-50 Area was delivered to the disposal plant of the K-25 Power House Area (Book II, Vol. 4).

c. Steam Heat. - A comparatively small amount of steam was diverted from the Main Process Building for heating purposes in the auxiliary buildings. Steam for heating fuel oil lines was obtained from Boiler Plant No. 2.

d. Electrical Supply. - Electrical power was supplied to the S-50 Area from the K-25 Power House (Book II, Vol. 5) by way of a 13.2 KV underground cable which led to a 7500 KVA 13200- to 2300- to 440-volt transformer at the S-50 switch house (App. E1). Five main lines carried secondary current at 2300 volts directly to cubicles in the Main Process

Building, the New Boiler Plant, and the pump house. An auxiliary power supply was provided by installing an additional cable from the K-25 Power House directly to the 2300-volt bus in the S-50 switch house, where automatic relays insured an additional source of power in the event of a failure in the main S-50 transformer. Originally the low voltage power at 440 volts was supplied directly from the K-25 Power House to S-50, but during the early stages of operations, it became apparent that a large block of additional 440-volt power would be required for auxiliary equipment throughout the S-50 Area; therefore, provisions were made to utilize the 440-volt taps on the S-50 transformer. An auxiliary tie with the 440-volt bus in the K-25 Power House was also provided, making a similar auxiliary system on both the 440- and 2300-volt systems. 110- and 220-volt currents, for lighting and small appliances, were obtained from small individual transformers, located throughout the S-50 buildings. The primary system, to the low side of the switch gear, was designed by the Kellex Corporation (App. C19) and installed by the J. A. Jones Construction Company and the A. S. Schulman Electric Company. The power and lighting systems, from the low side of the switch gear to various sections of the plant, were designed and installed by the H. K. Ferguson Company, under their original contract. Connected load was about 6000 KVA at 2300 volts, and 740 KVA at 440 volts. The street lighting system in the S-50 Area was installed by the A. S. Schulman Electric Company, in connection with the street lighting system of the K-25 Power House Area. Power and light currents were distributed to the various buildings in the area by underground cable from the switch house at 440 volts, and transformed for lighting at the various buildings. A fire alarm system was installed as

a part of a general layout covering the K-25 Area.

e. Rail Transportation. - A branch of the Southern Railway connecting with the main line at Blair, Tennessee, served the S-50 Area.

f. Water Transportation. - The S-50 Area was situated on the bank of the Clinch River, between Watts Bar Dam and Norris Dam. Barge transportation was possible from points below, as a part of the Inland Waterway System, connecting with all points on the Mississippi River system, but this means of transportation was utilized only in the shipment, from Galveston, Texas, to the S-50 Area, of the twelve pre-erected destroyer escort boilers for the New Boiler Plant. Oil shipment by barge was contemplated but rail transportation was used because of a severe barge shortage.

SECTION 5 - OPERATIONS

5-1. Selection of Operations Contractor. - When the H. K. Ferguson Company was selected to construct the S-50 Project, it was the desire of the District Engineer that this company design and operate the plant, procure the equipment, and construct the facilities. It was the opinion of the District Engineer that, since the S-50 Project was relatively small and highly secret, and since the prime requisite was early production (Par. 3-1a), the best results could be obtained by having a single organization perform all the functions as noted above. However, in order to have the plant operate under policies in effect at other plants in the District, it was necessary to follow non-union or open-shop practices in operations. Since the H. K. Ferguson Company always operated on a closed-shop basis, either with or without agreements with the various trade-unions involved, the company naturally expected labor difficulties on their many construction projects if they were to attempt to operate this plant with non-union labor. The contractor, therefore, asked for permission to form an operating company to be known as the Fercleve Corporation, the name indicating "Ferguson of Cleveland". Approval was granted, and separate contracts were negotiated for construction and operation. The H. K. Ferguson Company constructed the plant, and the Fercleve Corporation operated it. The Fercleve Corporation was a totally-owned subsidiary of the H. K. Ferguson Company.

5-2. The Fercleve Corporation Contract. - By means of letter-contract No. W-7409-eng-100, dated 1 July 1944, the Fercleve Corporation was authorized to do all things incident to the procurement of supplies

and materials, training of personnel, and inspection, supervision, and operation of the S-50 plant. A formal cost-plus-fixed-fee contract, patterned after operating contracts let by the Ordnance Department, was subsequently negotiated. The H. K. Ferguson Company originally estimated operational cost at $6,048,000 per year and the Fercleve Corporation fee was set at $11,000 per month. The specifications for final product were set forth in the form of a "secret" letter from the District Engineer (Appendix D3).

5-3. Specifications of Final Product. - The minimum concentration of Uranium-235 in the product was specified to be 1.20 times its isotopic concentration in the raw material. In the spring of 1945, at the order of the District Engineer, the Fercleve Corporation Technical Division carried out extensive surveys regarding optimum product concentration and production rate (Appendix G21). Results did not warrant a change in the original specifications, which remained in effect throughout the period of S-50 operations.

5-4. History of Operations. - The first work on conditioning a rack for operation was begun on 10 September 1944. However, proper operation was achieved very slowly because of continual difficulties encountered during the months of September and October. Handicapped by a lack of pilot plant experience, trained personnel, and sufficient steam, the Fercleve Corporation was also plagued by high pressure steam leaks, and leaks of process material. It was not until January 1945 that these difficulties were ironed out sufficiently to allow these racks under operation to operate on an efficient basis.

a. Personnel Training at Philadelphia Pilot Plant. - Near the end of August 1944, four Ferceleve Corporation employees and ten Army enlisted men (members of the Special Engineer Detachment, Manhattan District) were assigned to Dr. Abelson at the Philadelphia Pilot Plant (Par. 2-3e), to be trained as the nucleus of an operations organization. These men were trained to condition racks and to handle process material, but they gained little or no experience on an operating unit, since, at that time, the Philadelphia Pilot Plant was just being prepared for operation.

b. Pilot Plant Explosion. - The training period was cut short on 2 September 1944 by a disastrous explosion due to equipment failure (App. G22) which seriously damaged the Pilot Plant installations and injured several of the trainees. Dr. Abelson, fifteen members of his staff and the trainees, then proceeded to the S-50 site to assist in starting up the plant.

c. Preliminary Operations. - On 10 September 1944 work was begun on conditioning of Rack No. 21 which was the first operating unit installed. The rack at this time was in the intermediate stages of construction, and operators were hampered by the state of confusion which existed. As soon as a column was put into place by riggers and installed by pipe-fitters, it was immediately pressure tested and conditioned by operators. Welders, pipefitters, sheet metal workers, riggers, electricians, carpenters, and operations personnel were all feverishly working on adjacent portions of the unit. The application of 1000 p.s.i. steam to Rack No. 21 was a risky undertaking; faulty welding and troublesome fittings permitted large amounts of high-pressure steam to escape. The resultant noise made verbal communication impossible, and clouds of vapor prevented approach to many parts of the rack. How-

ever, owing to the great need for production, the rack was operated in spite of these conditions which under orthodox plant procedure would have called for an immediate shutdown.

d. Initial Production. - On 18 October 1944 the first material was introduced into Rack No. 21. Because of operational difficulties, however, the first product was not obtained until 30 October. At 2300 on that date, material was tapped from the tops of the individual columns into a small nickel capsule, after a laborious operation.

e. Large-Scale Production. - Rack No. 21 was operated until 15 December 1944, serving principally as a training unit. In the meantime, Racks 19 and 20 were started up, but ruptured material lines forced shutdowns. On 15 December 1944 operations were moved to Racks 11, 12, 13, and 14. By 15 January 1945, ten out of the completed twenty-one racks were producing. The remaining racks were placed in operation one by one as fast as minor piping and welding changes could be finished, preliminary conditioning could be completed, and trained operating personnel could be obtained. By the end of January 1945, thirteen racks were in various stages of operation, and this number gradually increased, though interrupted by numerous shutdowns, until 15 March 1945, when all twenty-one units were yielding product.

f. Production Record. - Appendix A7 presents a graphical record of plant production by months in terms of percentage of original theoretical maximum output. The monthly and total production figures are tabulated in the Top Secret Supplement.

5-5. Method of Operation. - All process activities were centered around two major objectives: to keep the bottoms of the columns con-

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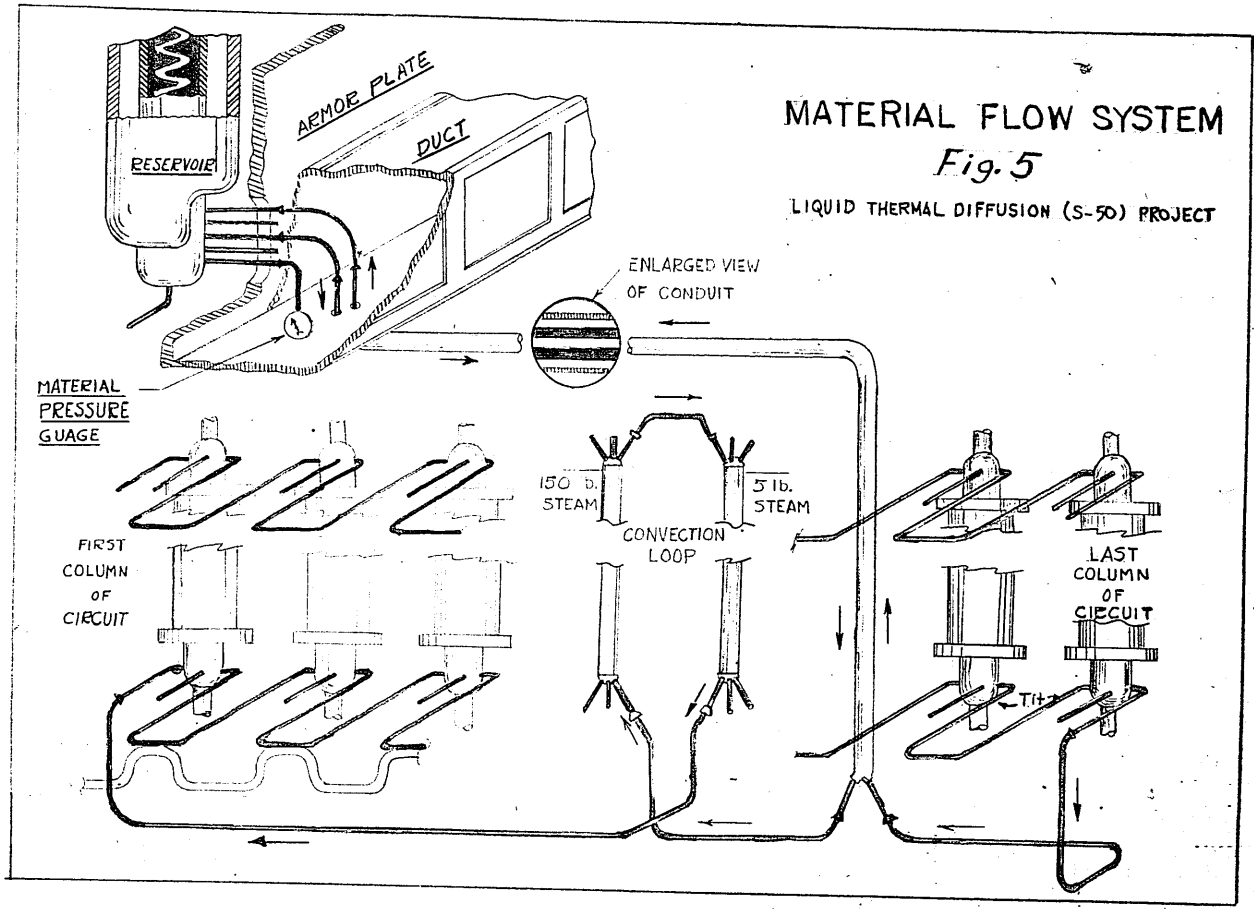
MATERIAL FLOW SYSTEM

Fig. 5

LIQUID THERMAL DIFFUSION (S-50) PROJECT



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tinually supplied with adequate feed material, and to withdraw product material intermittently from the tops of the columns. In S-50 parlance these two operations were known respectively as "circulation" and "milking". In normal operation a continuous flow of process material took place from the reservoir through a steam-jacketed nickel conduit, through a convection loop and the bottoms of the columns, then back through another conduit to the reservoir (Fig. 1 facing p. 2.13; Fig. 5). Some of the material exchanged with material in the columns where the desired process took place. At the tops of the columns, the product was removed by one of several product withdrawal methods. After a certain period of time during which the material was circulated along the bottoms of the columns, the reservoir was emptied of depleted material while the rack was connected to a freshly filled reservoir, so that the separation process in the columns could be continued. The actual process taking place in the column was not dependent on the circulation of the material through the bottoms of the columns. However, it was absolutely necessary that fresh material be kept flowing in this manner, or the separation process in the annular spaces of the columns would soon slow down or even come to an equilibrium standstill.

a. Rack Procedures.

(1) Freeze-off Techniques. - One of the primary techniques in routine operation was the simple "freeze-off" procedure which was used to stop the flow of material at any point or to isolate any part of a circuit. This novel valving technique merely involved lowering of the temperature of the desired process line or tit below the freezing point of the material, 155°F, by using cold water or "dry-ice".

Appendix B13 presents a photograph of a rack operator in the process of freezing off a convection line tit. During circulation, for example, the tops of the columns were isolated from each other by freezing the intercolumn connecting lines by means of cold water flowing through copper tubing brazed to the nickel material lines. Figure 5 is a simplified diagram indicating the method of connection of adjacent columns in a circuit. The copper freeze-off lines are shown only in the lower left portion of the diagram. These intercolumn connectors were fabricated at the site in large quantities. The design was improved in later work by passing the nickel line through the interior of the copper tubing instead of simply brazing it to the outside. In this way more efficient cooling was obtained, and the amount of brazing required was greatly reduced. The small internal diameter (from 1/16 to 3/32 inch) of the tubing and openings in the material system permitted the formation of plugs of frozen material which were sufficient to hold back pressures on the order of 1500 p.s.i. The cross sectional area of the plug so formed was such that the total force operating to blow the plug out of an open tit was only about four pounds. When it was necessary to open a circuit under pressure, as when replacing a plugged line, changing to a fresh reservoir, taking a sample, withdrawing product, etc., a lump of dry ice was placed against the material line both up- and down-stream from the part being worked on, to insure thorough freeze-off isolation.

(2) Elimination of Plugs. - In order to operate at maximum efficiency, a circuit needed as many hours a day of unobstructed circulation as possible. Therefore, the general problem of locating and

eliminating plugs from the many narrow apertures in the closed process circuits was one of the most important in plant operation. The circuit consisted essentially of a lengthy series of 1/16 and 3/32 inch diameter lines and passage ways. If the temperature in any part of the system fell below the freezing point of the process material, solidification would stop circulation; this type of plug was easily remedied by heating the point in question. Obstruction of a more serious nature resulted from sediment such as nickel and copper filings, from traces of solid uranium tetrafluoride impurity, and particularly from nonfusible reaction products of uranium hexafluoride with contaminating moisture and organic matter. Techniques for locating and removing these obstructions were developed which involved variation of reservoir pressure, and correlation of resulting pressure readings at the rack (App. G23). After locating an obstruction approximately, it could often be dislodged and flushed clear by rapidly varying the process material pressure, or in more severe cases by suddenly withdrawing from one to five pounds of material into a nickel capsule. As a last resort, the nickel line, column tit, or other piece in question was removed and replaced by a new freshly conditioned item (App. B12).

(3) Prevention of Intercolumn Mixing. - When the connections between the tops and bottoms of adjoining columns were thawed simultaneously, small differences in column temperatures tended to sweep material up one column and down another in a manner similar to the action of the convection loop. Obviously, this flow carried the relatively depleted material up into the enriched regions and forced the collecting product down into the leaner regions. Such intercolumn mixing was most undesirable as it nullified any previous isotope separation, and was ruinous to rack production. During normal circulation

across the bottom of the rack, it was therefore vitally important to keep all columns isolated from one another at the top. Similarly during product withdrawal, when all columns were connected at the top, they had to be isolated at the bottom. Unless the utmost precautions were taken to keep the proper intercolumn connectors frozen off, intercolumn mixing could easily be caused between two or more columns by slight variations from column to column in annular dimensions, steam pressure, or heat transfer coefficient. (In plant operation this phenomenon was usually called "intercolumn circulation").

(4) Prevention of Pitching. - If the process pressure was not carefully controlled, a rather violent bubbling or boiling occurred within the annular spaces of the columns; and this extremely troublesome phenomenon was referred to as "pitching". When the material pressure was allowed to fall from the normal value of 1500 p.s.i. to 1200 p.s.i. or below, this swirling and turbulent motion occurred spontaneously and completely disrupted the slow, steady, and orderly accumulation of enriched material at the tops of the columns. Pitching was recognized by a noise or vibration within the columns ranging from a feeble murmur to a pronounced rattle and was accompanied by a sharp rise of steam consumption, cooling water temperature, and rate of flow of make-up water. Apparently, the rapid alternating lateral flow of material between the hot and the cold walls of the annular spaces, accompanied by sudden changes in heat content and state of aggregation, increased the rate of heat transfer. Since lowered pressure increased the likelihood of pitching, it was desirable from that viewpoint to operate at as high a pressure as possible. On the other hand,

the greater the pressure, the greater was the bursting stress and resultant strain on the columns, reservoirs, and all parts of the circuit. Also, increased pressure caused increased viscosity and tended to make circulation more difficult. A compromise therefore established 1500 p.s.i. as standard operating material pressure. The process pressure was controlled by throttling the steam supply to the reservoirs down to a value dependent on the particular weight of material contained in them. Transfer room operators regulated the material pressure and maintained a constant check to prevent the occurrence of pitching. For example, the circuit pressure was raised to 1700 p.s.i. before each milking because the withdrawal of a pound of material from a closed process circuit would result in a sudden pressure drop of about 200 p.s.i.

(5) Product Withdrawal Procedures. - In order to withdraw product in small increments from a circuit of columns, a milker was installed at the top of each circuit, which consisted of two freeze-off coils, a metering capsule, and a receiver capsule (Fig. 4 facing p. 4.5). Because of the material pressure in the columns, product flowed through the first freeze-off coil, when its water was shut off, into the metering capsule. The first coil was then re-frozen, and the second coil thawed. This allowed the product to flow out of the metering capsule into the receiver capsule. The milker could be operated by hand, semi-automatically, or fully automatically. When operating by hand, the operator worked at the rack, opening and closing freeze-off water and compressed air valves in proper sequence with due allowance of time for the solidification and thawing of the material in the freeze-off coils. The readings of material pressure gauges and the receiver

capsule scale gave an indication of the completion of a milking. When operating semi-automatically, the operator worked from the control room where a bank of switches controlled the opening and closing of a series of solenoid valves which were inserted in the freeze-off water and air lines in series with the hand valves mentioned above. When operating fully automatically, the switching schedule was taken care of mechanically by means of a cam timer which was set to run through the step by step sequence of freezing and unfreezing the intercolumn connectors at the top and bottom of the rack circuit as well as the two freeze-off coils of the milker. (See Top Secret Supplement for withdrawal schedules.) Because milking necessitated a periodic interruption in circulation, milking schedules were aimed at minimizing the time necessary for this operation so that normal circulation through the bottom of the rack could be resumed as soon as possible. In an attempt to simplify and improve product withdrawal procedures, the "top-circulation" or "Dole method" was devised and studied. Instead of bleeding off the desired product in short, even increments into a small capsule, this system involved the withdrawal of enriched material by intermittently circulating it across the tops of the columns and through a 65-pound high pressure container, where it gradually displaced raw material until the mixture reached the specified product concentration. The method was convenient, and at first showed great promise because it simplified operation, reduced manpower requirements, and eliminated the sudden, undesirable 200 p.s.i. drop in pressure which occurred with the usual method of milking. However, since it was necessary to interrupt bottom circulation by freezing off intercolumn connections to prevent intercolumn mixing during the long periods of top

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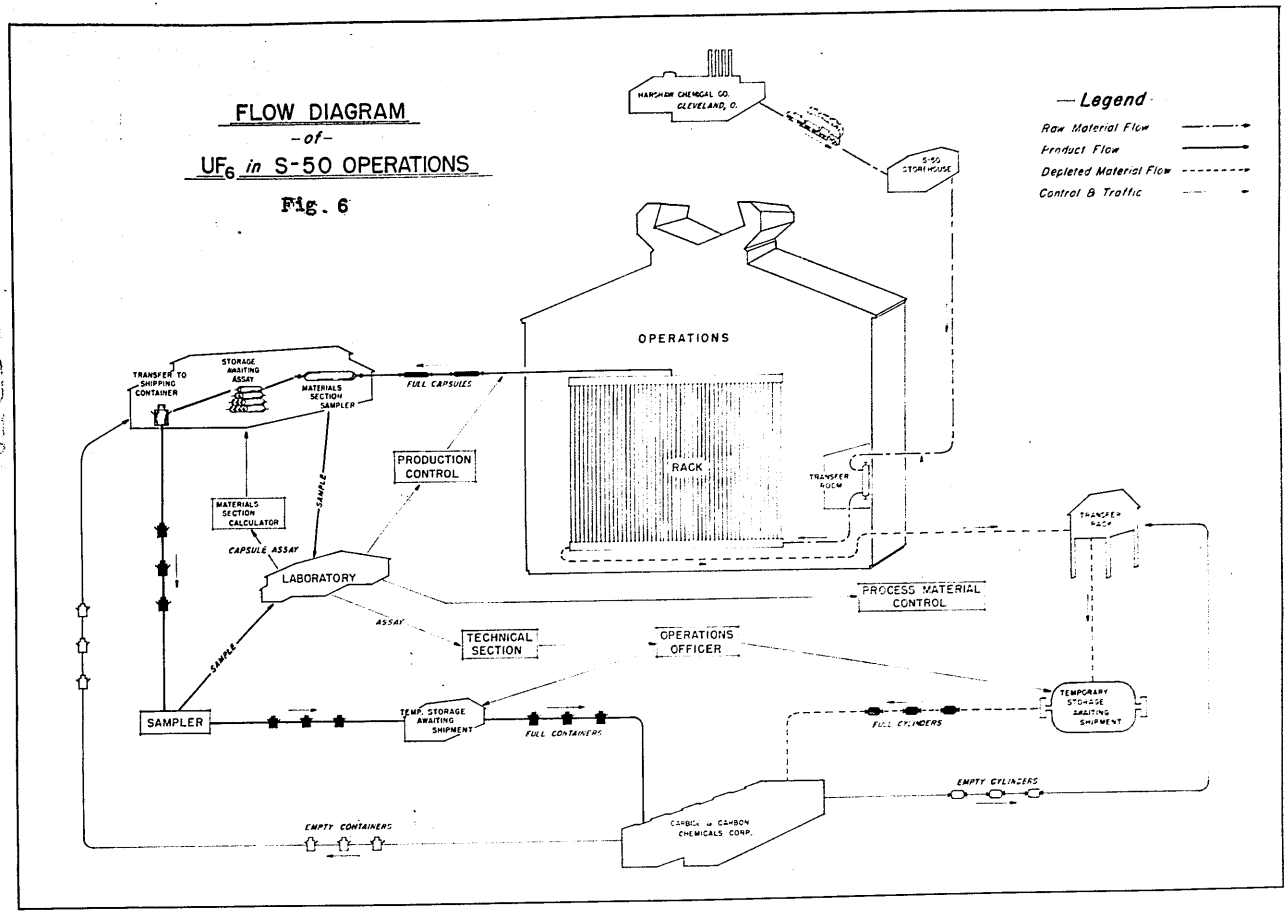
FLOW DIAGRAM
-of-
UF_6 *in* S-50 OPERATIONS

Fig. 6



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circulation, column productivity dropped, and racks using the Dole method gave about 20 percent less production than racks using capsule-milking. The method was therefore discontinued (App. G25).

b. Handling of Process Material.

(1) Raw Material. - Raw material (normal UF_6) was received from the Harshaw Chemical Company of Cleveland, Ohio, in a nickel cylinder containing approximately 450 pounds of the solid raw material (Fig. 6). Each cylinder was weighed by the chief warehouse man, its weight was checked against the accompanying shipping memorandum, and any large discrepancy was noted and reported to the Operations Officer. The cylinder of raw UF_6 was then stored in a special warehouse near the Main Process Building until needed. When taken from this warehouse, the raw material was introduced into the process equipment through the transfer room. The cylinder was jacketed in a "transfer pot" and connected to the reservoir by means of a steam-jacketed nickel tube. Steam was then introduced into the transfer pot jacket, while warm water filled the reservoir jacket, and the vaporized raw material in the cylinder was transferred into the reservoir as a result of the difference in vapor pressure in the two vessels. The cylinder of raw material was supplied to the transfer room by a materials handling crew which was organized for this purpose, and delivery was made from warehouse to transfer room on request. The full reservoir was held idle until needed and then connected to the rack by means of conduit lines. In any operation of this nature where solid UF_6 enclosed within a rigid container was to be thawed, careful consideration had to be given to the large volume change which the material underwent when passing from a solid at

room temperature to a liquid at the melting point. Unless space was provided to allow for some 35 percent expansion, dangerously high hydraulic pressures developed. Thus if a region of local overheating occurred, where melting material was totally enclosed by retaining walls and surrounding unmelted material, local pressure could cause rupture of the container wall. It was therefore very important to take precautions to avoid development of high temperature zones at points where there was no access to free volume. A second consideration involved in loading process fluid into containers at relatively low temperatures and high densities, was its high rate of change of pressure with temperature. If a container was overloaded at low temperature, the pressure would exceed safe limits when the material was brought up to process temperature. There was a definite maximum safe capacity for each particular vessel which was not to be exceeded. 420 pounds of raw material was specified as the limit for a standard reservoir, since experiment showed that if 1000 p.s.i. steam was turned into the heating coil without throttling, with 420 pounds of material in the tank, the material pressure would rise to 2500 p.s.i., which was the maximum safe working pressure for the vessel.

(2) Salvage Material. - "Salvage", not shown on the accompanying flow diagram (Fig. 6), since it was a result of an obstruction or breakdown in the process system, was the term used to designate material withdrawn from the process units in any of several ways: in draining broken or by-passed columns, in hunting for obstructions which interfered with circulation of the process fluid, and in draining convection or conduit lines, to name a few. In general, any material of concentration intermediate between that of depleted material and that of

product, was classed as salvage. It was normally withdrawn in small capsules containing a net weight of from one to five pounds. The contents of these capsules were dumped into steel acetylene cylinders, without sampling. After a considerable quantity of salvage material had been accumulated in an acetylene cylinder (a net weight of between three and four hundred pounds), samples were taken and assays were run on these samples. If the assay of the salvage was at or above that of raw feed, it was returned to the process to be reworked, entering the system in the same way as did raw material. Salvage which showed a lower concentration in the same range as that of depleted material was dumped to depleted material storage.

(3) Losses of Material. - UF_6 escaping from the process into the air or cooling water could not be recovered, and was classed as "losses". Such losses were usually the result of internal or external breaks in columns or other parts of process circuits caused by failure of materials under the high operating pressures. Other losses resulted from improper handling of open connections and various operational mistakes.

(4) Depleted Material. - The material removed from the material reservoirs, after the proper proportion of product had been removed by action of the columns, was designated as depleted material. Its concentration was so low as to make further processing by liquid thermal diffusion undesirable. Depleted material was removed from the rack by a procedure which was very nearly the reverse of the addition of raw material. The material was emptied into standard steel acetylene cylinders, where it solidified into the non-corrosive solid state. The

concentration of the depleted material was determined by a material balance run on the entire cycle by the Process Control Section; and, normally, no sampling of this class of material was necessary. The acetylene cylinders were emptied into large, standard steel chlorine cylinders to a net weight not exceeding 4500 pounds. The chlorine cylinders were then shipped to the K-25 Area (Book II, Vol. 5).

(5) Product. - Product was that part of the feed whose isotopic concentration of Uranium-235 had been enriched by the action of the columns to 0.85 per cent, the concentration designated as "par" for the process (App. D3). It was obtained by the systematic removal of material from the tops of the columns, after the necessary time interval required for the separation of the isotopes. The small capsules of product material withdrawn from the circuits (See Top Secret Supplement for net weights.) were delivered to the Materials Section for disposal. Most of these capsules were sampled, and the samples were sent to one of the two laboratories for assay. Capsules which were not sampled were classified according to a system which designated their probable assay, as indicated by assay curves on the racks from which they were removed. As a result of assay information obtained on these product capsules, they were classified according to their assay ranges, and dumped into low-pressure shipping containers in such a manner that the assay on shipments could be controlled to a considerably smaller variation than that found in individual capsules received from the Main Process Building. This procedure was known as "blending." Some of the capsules of product received showed assays so low upon sampling that they could not be utilized as product, and the material thus obtained

was stored as salvage in acetylene cylinders and returned to the Process Building for further enrichment, being re-fed into the process system in the same manner as raw material. The product, after blending, was resampled to make sure that each shipping container was of satisfactory quality. If the resulting assays were acceptable (acceptance being determined by the Technical Division and the Operations Officer), the shipping containers, (See Top Secret Supplement for size.) were shipped to the K-25 Area (Book II, Vol. 5). Originally (Par. 1-1), S-50 product was utilized by the Y-12 Project (Book V, Vol. 6) but later developments caused the rerouting of S-50 product to the K-25 Plant (App. G34).

c. Control.

(1) Product Control. - The purpose of product control was to obtain the optimum in quantity and quality of production. By receiving assay reports from the laboratories on capsule samples or direct rack samples, the Product Control Section was in a position to know the condition and history of all the circuits on the racks at all times. This knowledge was necessary for the scheduling of product withdrawal and also for the detection of faulty equipment or errors in operating procedure. From records and performance graphs (circuit assays plotted against operating time), it was possible to predict probable assays of product withdrawals by studying previous performance, and thus effect the elimination of many samples. Broad general knowledge of the extent of damage done to the separation process by various functional failures of equipment or technique, and sound decision as to when normal product removal could be resumed after such a disturbance, were essential

to product control.

(2) Process Control. - Process control was concerned with the flow of material through the plant, from receipt as raw material to shipment as product. Weekly and monthly material balances were run on the plant, which required knowledge of all shipments into and out of the area, as well as physical checks of material in various stages of processing. By means of a daily material balance run on individual reservoirs, concentration of feed material in the process was calculated, and control figures were issued to be used as a basis for removal of depleted material and additions of fresh feed. An overall material balance was run on each depletion cycle to determine the efficiency of material use. Complete production records (App. G33) were maintained, including both weights and assays, which were utilized in preparing production and efficiency reports on the various production units for management, the District Engineer, and the Fercleve Corporation Technical Division. On the basis of predicted steam supplies, production estimates were prepared. While a large part of the work of process control was statistical, the need for accurate data influenced improvement of sampling techniques and operating procedures.

(3) Assay Laboratories. - There were two assay laboratories serving the S-50 Plant and they were designated as Laboratory No. 1 and Laboratory No. 2. Laboratory No. 1 determined the relative amount of the Uranium-235 isotope in a sample by means of a Nier mass spectrometer. Since the mass spectrometer method of assaying was comparatively rapid, all routine samples upon which the Product Control Section depended were assayed by this laboratory, which normally

turned out 120 assays per day. Although this laboratory had four machines, usually only two of them were operating at a time because of frequent shutdowns for cleaning of tubes and other repairs. The machines were developed at the University of Minnesota and were built by the General Electric Company. The accuracy of the assay was of the order of plus or minus one per cent of the value reported. However, the use of this laboratory was discontinued shortly before the S-50 Plant was placed in stand-by condition, since frequent breakdowns and comparative inaccuracy made this laboratory less efficient than Laboratory No. 2, which determined the relative amount of Uranium-235 isotope in a sample by counting the alpha particles emitted. This laboratory maintained an accuracy of about plus or minus 0.5 per cent and had a capacity of approximately 80 assays per day. Prior to the discontinuance of Laboratory No. 1, Laboratory No. 2 handled primarily shipment, depleted material, and Technical Division samples. After the shutdown of Laboratory No. 1, it handled all samples. This laboratory was patterned after the K-25 assay laboratories (Book II, Vol. 5).

d. Conditioning of Equipment. - In order to avoid contamination of product, and especially to prevent obstructions in the process lines, it was necessary to clean with the utmost care every item of equipment which could come into contact with UF_6 when placed in service (App. G24). Typical of the rigorous procedures set up for conditioning equipment were the following:

(1) Reservoirs - The first step was to dry the vessel by turning low pressure steam into the jacket and inner coil, at the same time blowing air through the body of the tank, and then evacu-

ating with a vacuum pump. This was followed in turn by fluorination* and the introduction of about eight pounds of process material, with steam connected to the inner coil. After removal of this "conditioning charge", the tank was washed out completely with water and rigorously dried by turning on high pressure steam, blowing with air, and evacuating. Finally, the vessel was blown with dry nitrogen, tested for moisture, fluorinated, and dried again, before filling with process material for use.

(2) Columns. - Conditioning fluids were fed either to individual columns or, through manifolds, to groups of columns in any number up to seventeen. Liquids were forced up the columns by applying air pressure to small portable enclosed mixing tanks, whereas air and nitrogen were ordinarily blown from the top of the column downward. Standard procedures were employed similar to those used on the reservoirs. In general, the columns were blown with air, rinsed with trichlorethylene or carbon tetrachloride to remove grease, washed with dilute hydrochloric acid to remove oxides, carefully dried, tested for moisture, and fluorinated.

(3) Auxiliary Parts. - Similar procedures were followed on minor items. For example, a new capsule, material pressure gauge, link line, or intercolumn connector was blown, degreased, fluorinated, and tightly capped until ready for use. All process equipment, other than columns, conduit lines, convection lines, and reservoirs, were conditioned in the Materials and Conditioning Shop. Furthermore, this section re-conditioned equipment for further use after removal from an operating circuit.

e. Supply of Utilities. - The function of supplying the plant utilities was handled by the Steam Department. Among its responsibilities was the steady supply of high and low pressure steam, cooling and freeze-off water, high and low pressure air, and propane gas. Personnel of this department operated circulating and make-up water pumps, condensate pumps, air compressors, desuperheating equipment, the entire New Boiler Plant, the Tank Farm, and the water treatment plant.

5-6. Factors Hampering Operations.

a. Steam Difficulties.

(1) Lack of Steam. - From the outset, lack of steam from the K-25 Power House was an important factor limiting plant production; this was partially anticipated in the design of the S-50 Plant. Not anticipated, however, were such K-25 Power House difficulties as inadequate condensate make-up capacity, drastically reduced output because of occasional wet coal, and inability to handle the large amounts of return condensate. The initially installed Power House facilities were not sufficient to handle the additional requirements imposed by S-50 operations.

(2) High-Pressure Steam Leaks. - A major problem arose from high pressure steam leaks, especially in the unions which connect the columns into the headers. Terrific thermal shock and the movement of the unions due to column expansion and contraction were factors contributing to these leaks. It was found necessary to cut out all the unions and replace them with welded pipe nipples. It was the consensus that the unions came up to the specifications, but that the

unions specified were inadequate. The unions were identical with those on the hitherto unoperated Pilot Plant rack. When that installation was started up, the unions were also found to be inadequate, and were replaced with welded pipe nipples.

(3). Design Changes. - Changes in design were necessary, both in the Main Process Building and the Power House, to increase the efficiencies and capacities. The re-piping of the low-pressure condensate return system, the installation of safety valves on the low-pressure header, the installation of cooling water lines to the desuperheating pumps, the removal of many unions from rack piping, and the re-piping of conduit and convector lines on the racks, were instrumental in increasing production.

b. Lack of Pilot Plant Experience. - Although at the time of S-50 construction a 1000 p.s.i. steam rack was under construction in the Pilot Plant, process material pressure in the region of 1500 p.s.i. was quite novel and the proper operating techniques had not been developed.

c. Lack of Trained Operating Personnel. - It became evident very early that the Fercleve Corporation would be unable to secure, in the short period of construction, sufficient technical personnel to assist in putting the plant into operation. Accordingly, from September 1944 to January 1945, enlisted members of the Special Engineer Detachment, who were trained in engineering and the sciences, were assigned to the Fercleve Corporation. While this measure only partially offset the lack of technical personnel, it is very doubtful that the plant would ever have been successfully operated without the aid of these

soldiers. Also, Dr. Abelson sent about fifteen Naval men to the site for a short period in September and October, and they, too, were of great help. The assistance of both these groups was particularly necessary during the intense activities of the preliminary operations when the most workable techniques were just being developed. In that period the ability to meet the many unpredictable situations which arose daily was essential, for several months had passed before really adequate training in operations was possible for new employees (Par. 5-7c).

5-7. Industrial Relations.

a. Labor Procurement. - In order to meet the personnel requirements in the various divisions, an employment schedule was set up by the Fercleve Corporation on the basis of personnel estimations from divisional heads. The Fercleve Corporation, accordingly, established employment offices in the S-50 Area, in the neighboring cities of Knoxville and Harriman, and in New York City. In addition, six roving recruiters were assigned to handle employment in areas out of the range of these offices, and aid was requested from the U. S. Employment Service in sections of the country not classed as critical labor areas. The workers were offered a guaranteed work week of forty-eight hours at the generally high wage level prevalent at the Clinton Engineer Works. However, throughout earlier operations, the rate of the personnel turnover was high because of the housing situation (Par. 5-7e) and other handicaps. In order to meet the employment schedule it was necessary, from the very beginning, to obtain many employees which the Fercleve Corporation could not recruit directly. These additional groups consisted of U. S. E. D. personnel, enlisted men for jobs where qualified

personnel could not be obtained, borrowed personnel from Carbide and Carbon Chemicals Corporation for the laboratories, and various other personnel who were given leave by employing colleges, oil companies, etc. For a graph showing the numbers of employees on the payroll during the twelve months of operations, see App. A10.

b. Wages and Hours. - A schedule of wages and salaries (App. G39) was prepared by the Fercleve Corporation and was approved in a letter from the War Wage Administration Agency (App. G28). The rates paid were based on the prevailing rates for the Clinton Engineer Works operations contractors. Reclassifications, complaints, and promotions were handled by means of a merit system, job descriptions, and rate analyses.

c. Schooling. - In order to provide adequate job training for new employees in operations, the Fercleve Corporation organized a training department in April 1945. During the two-week training period the men were given explanations of the operators' duties, experience in each main operation and a final comprehensive examination. A training course for supervisory employees was also instituted to provide instruction in dealing with personnel, methods of teaching operators and orienting new personnel, methods of inculcation of safety rules, etc.

d. Safety and First Aid. - Safety instructions and inspections at S-50 were assigned to the Safety Department of the Fercleve Corporation. In conjunction with this group, the neighboring K-25 Dispensary furnished the necessary medical personnel for first aid, health protection, physical examinations, and other medical services. Routine

cases were treated in the S-50 first aid building, but all patients requiring prolonged or specialized treatment were carried by ambulance to the nearby dispensary in the K-25 Area. K-25 also maintained adequate fire fighting equipment and personnel for the S-50 project (Book II, Vol. 5). The safety engineers of the Fercleve Corporation were responsible for preventing the operations hazards resulting from the following possible sources: (1) the high operating pressure of the steam and process material; (2) the high operating temperatures; (3) the poisonous and corrosive nature of the process material; (4) the radioactive nature of the process material; and (5) the conditions common to the average industrial plant. As a precaution against the first three types, all operating personnel were furnished with gloves, coveralls, and long-sleeve heavy underclothing. It was known that the double layer feature of protective clothing was especially effective in preventing burns caused by escaping process fluid. Face shields and goggles protected against steam or chemical burns around the face and eyes; but in the event that an operator was sprayed by process material, special sinks and showers were available throughout the plant for immediate use. Furthermore, every operator was required to have a gas mask on his person at all times for emergencies, such as, serious breaks, which would result in large quantities of vaporized UF_6 accompanied by oxyfluoride dust fumes, and hydrofluoric acid mist. Forced ventilation was installed to prevent any ill effects on personnel trapped in the transfer or control rooms during a break. A steel armor plate was built up to form an enclosing barrier around the bank of reservoirs in each transfer room in case of tank failure under operating pressure. The hard hat was worn

as a protection from falling objects or projections often present when operation and construction were going on side by side. Measurements taken throughout the plant showed the presence of radiation only in amounts well below the range accepted as physiologically safe (App. G36). Although the Fercleve Corporation frequency rate of 13.98 was above the overall average of 7.41 for the Clinton Engineer Works, the severity rate of 0.38 was below the overall Clinton Engineer Works value of 0.74. Both the frequency and severity rates were well below the national average (App. D8).

e. Housing. - Allocation of houses and other domiciles was handled by the "Central Facilities" organization (Book I, Vol. 12) of the Clinton Engineer Works. Because of the relatively late decision to construct the S-50 Plant, and because of the speed of construction which was necessary, incorporation of S-50 housing into the overall Clinton Engineer Works planning program for housing units was not feasible. Since it was intended that the S-50 Project should be a temporary expedient until K-25 could get into production, utilization of houses allocated for K-25 operators was contemplated; however, the long-range personnel training of the K-25 Area operators and the eventual overlapping of the operating periods invalidated this scheme. The need for additional housing by the entire project was recognized late in 1944 and steps were taken immediately to provide a considerable number of housing units, some of which were made available to the Fercleve Corporation. This did not completely solve the housing situation, and the lack of sufficient living quarters was a factor contributing to the difficulty in obtaining operating personnel. Single and

double trailers, hutments, victory cottages, and some permanent type units were utilized, and by the termination of operations on 4 September 1945, the Fercleve Corporation had received 58 houses, 166 trailers, and 358 dormitory rooms. About fifty percent of the employees lived outside of the Clinton Engineer Works area, in War Housing Centers and in adjacent communities.

f. Transportation. - Bus transportation was available for all the S-50 employees in commuting to and from work, but the crowded bus service was a frequent source of contention. In order to make gasoline and tires available for employees driving their own cars, it was necessary to set up a ration board which operated in conjunction with the boards established to serve the employees of the K-25 Area. For official use government-owned automotive equipment was assigned to the Fercleve Corporation.

g. Working Conditions. - Because of simultaneous construction and operation in the Main Process Building, early working conditions entailed certain difficulties and inconveniences. However, despite such inconveniences as high-pressure steam and material leaks, serious occupational injuries were very few. In the first months of operation the workers were annoyed by lack of adequate change house and cafeteria facilities, and by constant rain and mud. A new cafeteria, improvements in the change house, and improved roads and walks later relieved the situation.

5-8. Security. - An overall security program was worked out by the Fercleve Corporation, in co-operation with the District Intelligence and Security Officer, that met all U. S. E. D. requirements. The pro-

gram included the maintenance of security with respect to plant facilities, with respect to personnel, and with respect to the safeguarding of military information. Plant security was maintained by an identification and control system, with the aid of an adequate guard force which cooperated with the K-25 guard forces, in guarding borders common to both areas. The utmost caution was exercised in providing for security with respect to personnel. An amplified personal history report was secured through credit reference bureaus on each employee, and appropriate action was taken on all derogatory information received. A personal security questionnaire (W. D. Form 58) was also filled out by each employee, and both of these reports were transmitted to the District Intelligence Office for obtaining proper clearance for the prospective employee. All employees were then required to sign secrecy of information pledges, at the time of their initial employment and at their exit security interviews. In addition, lists of key personnel were transmitted to the Area Intelligence Office for special investigation. Security of military information was effected by a thorough security educational program which included security supervisors appointed in each division office and work section.

5-9. Shutdown.

a. Termination of Operations. - As the result of several studies by the District Production Control Section (App. G38) on the various ways of operating Y-12, K-25, and S-50, to produce the maximum amount of final product in the most efficient and economical manner, it was decided after the defeat of Japan to shut down the S-50 Plant and to place it in stand-by. The different analyses indicated that

the S-50 process had been an economical production method for preliminary separation until the increased capacity became available at particularly Y-12 and K-25, but that use of S-50 was no longer advantageous except for all-out production where efficiency and economy were secondary considerations. With the close of hostilities, the policy of the Manhattan District was changed to emphasize economy rather than all-out production; and from this over-all viewpoint, it was decided that the enlarged K-25 Plant should handle the entire first stage of isotope separation (Book II, Vol. 5). Therefore, on 4 September 1945, instructions were issued to terminate all operations at S-50 and to place the equipment in stand-by condition for possible future operation (App. D7). Individual operating racks were shut down gradually so as to obtain the maximum amount of product from the holdup in the system. As the racks were shut down, the columns were drained of process material, flushed with nitrogen, washed with water, dried with dry air, and capped. Concurrently, pumps, motors, and accessory equipment were placed in stand-by condition. By 9 September 1945, all racks were shut down. A manual was prepared, describing in detail the steps which were taken to protect and preserve equipment, and the exact status of all items (App. G35).

b. Termination of Employees. - All employees were given two weeks notice as of 4 September 1945. At the expiration of this two-week period, voluntary terminations had reduced personnel to approximately 900 employees. On 18 September, termination of all employees not essential to the work of placing S-50 in stand-by was begun. At the end of the month, 241 employees remained on the Feroleve pay roll.

Throughout October, November, and December, this number was continuously reduced until 1 January 1946, when there were approximately 30 employees remaining in the property and accounting sections. On 16 February 1946 the acting project manager paid off the last employee and departed for the home office in Cleveland to prepare the final fee proposed for submission to the District Settlement Review Board.

c. Disposal of Buildings and Equipment. - The entire area was transferred to the custody of the K-25 Operations Officer for the purpose of relieving the Fercleve Corporation of responsibility and accountability. The Tank Farm was transferred on 23 October 1945, and Laboratory No. 2 was transferred on 25 October 1945. All other buildings charged to Fercleve were transferred on 31 October. All spare parts specifically designed for the S-50 Plant were retained on the area, whereas other surplus material and equipment were disposed of in accordance with existing directives (War and Navy Departments' "Joint Terminations Regulations"). The security of the entire area was assumed bythe K-25 guard force.

d. Disposal of Records. - In all the record disposals, the procedure given in the District Circular Letter MI 45-14 was followed. All classified records, reports of research projects, and the technical data of the Fercleve Corporation Technical Division were placed in the custody of the Records Retirement Section of the Manhattan District. Unclassified records, blueprints, sketches, etc. and duplicate copies of classified records were destroyed or retired.

5-10. Summary of Operating Costs. - The total of the over-all S-50 operations expenditures as of 1 June 1946 was estimated by the

District Cost Section to be $6,992,616. A detailed list of the estimates for the Fercleve expenditures and fees and for the Government-supplied material, labor, etc., may be found in App. D5. Below is a tabulation of rough estimates for S-50 operating costs during most of the months of operation. (App. G37). There is presented in the Top Secret Supplement a tabulation of production figures for these months and a corresponding calculation of unit costs for S-50 product.

Month	Fercleve Cost	K-25 Steam & Electricity Cost	Total Cost
January	$300,000	$165,000	$465,000
February	435,000	261,000	696,000
March	493,000	291,000	784,000
April	743,000*	395,000	1,138,000
May	450,000	290,000	740,000
June	406,000	338,000	744,000
July	530,000	69,000	599,000

*The large increase in cost from March to April is due to the inclusion of five weekly payrolls in April rather than the usual four and also to large Government transfers of material during April.

SECTION 6 - ORGANIZATION AND PERSONNEL

6-1. Introduction. - Army, Navy, and civilian organizations were engaged in the S-50 Project. The Manhattan District was responsible for administration and supervision of the S-50 Project; design, construction, and operation of the plant were performed by contracting firms under contracts let by the Manhattan District. Because of the research originally begun by the Naval Research Laboratory, that organization cooperated extensively with the S-50 Project.

6-2. Naval Personnel.

a. Naval Research Laboratory Organization. - Although formerly under the Bureau of Ships, the Naval Research Laboratory is now under the Naval Office of Research and Invention. The Director of the Office is Rear Admiral Bowen, while Rear Admiral Van Keuren is Director of the Laboratory. Dr. P. H. Abelson is Head of the Special Research Division, and is Admiral Van Keuren's representative(Book I,Vol.1).

b. Naval Personnel Concerned with S-50 Project. - Dr. Philip Hauge Abelson, Naval Research Laboratory physicist, was responsible for the successful development of a practical process for separation of the uranium isotopes by means of liquid thermal diffusion, as well as the invention of the first practical method of large-scale preparation of uranium hexafluoride. He also spent a great amount of time at the S-50 site, helping to get the plant into successful operation. In order to provide an organization nucleus of sufficient size to permit thorough training of initial Fercleve employees, and to guide the initial S-50 operation, about fifteen men from the Naval Research

Laboratory accompanied Abelson to the site in early September 1944.

6-3. Manhattan District Personnel.

a. Officer Personnel.

(1) Contracting Officer. - As District Engineer, K. D. Nichols, Colonel, C. E., was the Contracting Officer for the S-50 Project.

(2) Unit Chief. - M. C. Fox, Lt. Colonel, C. E., was assigned to the S-50 Project as Unit Chief, 25 June 1944. As the Contracting Officer's Authorized Representative, he supervised all engineering, procurement, construction, operation, and process development. Lt. Col. Fox was transferred to another assignment in the District on 31 March 1945. Thos. J. Evans, Jr., Major, C. E., became Unit Chief on 1 April 1945 and assumed all responsibilities formerly held by Lt. Col. Fox. (Major Evans, as Construction Officer under Lt. Col. Fox, had supervised the construction and installation of the equipment at the site.) When Major Evans left on 26 November 1945, by which time the plant had been placed in stand-by condition, Captain G. L. Agnor took charge of the unit as Executive and Administrative Officer. This position was held by Lt. C. H. Gerow, Jr., USNR, from 5 February until his death on 20 May 1946. For Organization Chart see Appendix A3.

b. Enlisted Personnel. - Enlisted personnel of the Special Engineer Detachment of the 9812th Technical Service Unit contributed largely to the operational success of the S-50 Plant. These men, all of whom were trained in engineering or the sciences, worked originally as operators, and later as supervisors, with a zeal which set an admirable example for the civilian employees with whom they worked side by side.

The number of enlisted men assigned to S-50 at one time reached a peak of 126.

6-4. Major Construction Contractors. - Mrs. Ethel Hancock Ferguson, as First Vice-President and majority owner, was responsible to the War Department for H. K. Ferguson Company performance. W. N. Thompson was Chief Engineer, and as such had direct charge of all engineering. C. W. Roberts was Project Manager, and was responsible for all field work and departmental management. The H. K. Ferguson payroll reached a peak of 1900 in September 1944. For Organization Chart see Appendix A5. J. E. Davidson, as Project Manager for the work on the New Boiler Plant, had charge of the work on this phase, for the J. A. Jones Construction Company.

6-5. The Fercleve Corporation. - The Fercleve Corporation was a totally owned subsidiary of the H. K. Ferguson Company, organized for the purpose of operating the S-50 plant. C. W. Roberts was General Manager, R. S. Lamie was Production Superintendent, and Dr. B. F. Dodge was Director of Technical Division. The Fercleve Corporation payroll reached a peak of about 1600 operating people in April 1945, exclusive of military personnel. For Organization Chart see Appendix A4.

MANHATTAN DISTRICT HISTORY

BOOK VI - LIQUID THERMAL DIFFUSION (S-50) PROJECT

APPENDIX "A"

MAPS, CHARTS, DRAWINGS, AND GRAPHS

No.	Title
1.	Map of Clinton Engineer Works
2.	Map of S-50 Plant Area
3.	Military Organization Chart
4.	Operations Organization Chart
5.	Construction Organization Chart
6.	Floor Plan of Main Process Building
7.	Production Chart
8.	Construction Graphs
9.	Graph of Construction Personnel
10.	Graph of Operations Personnel

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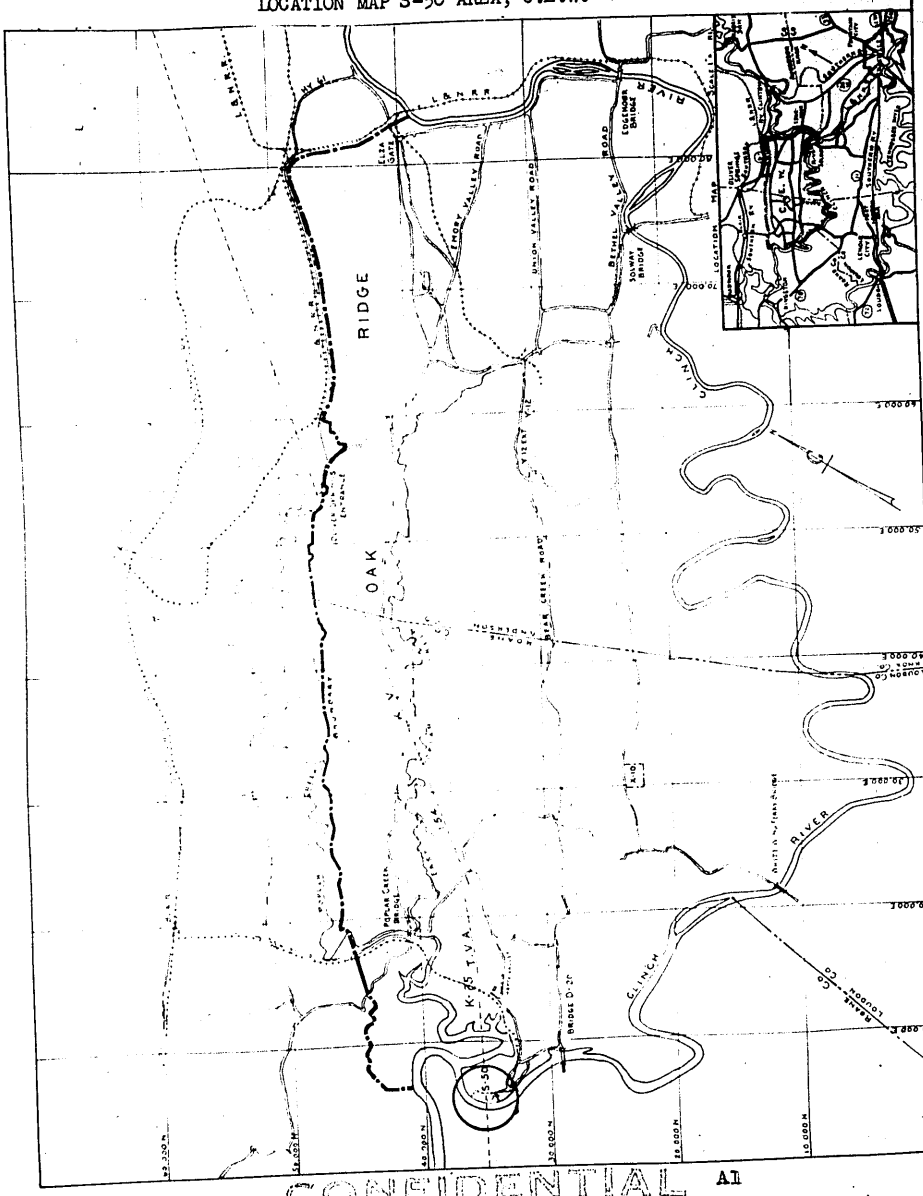
CONFIDENTIAL

LOCATION MAP S-50 AREA, C.E.W.



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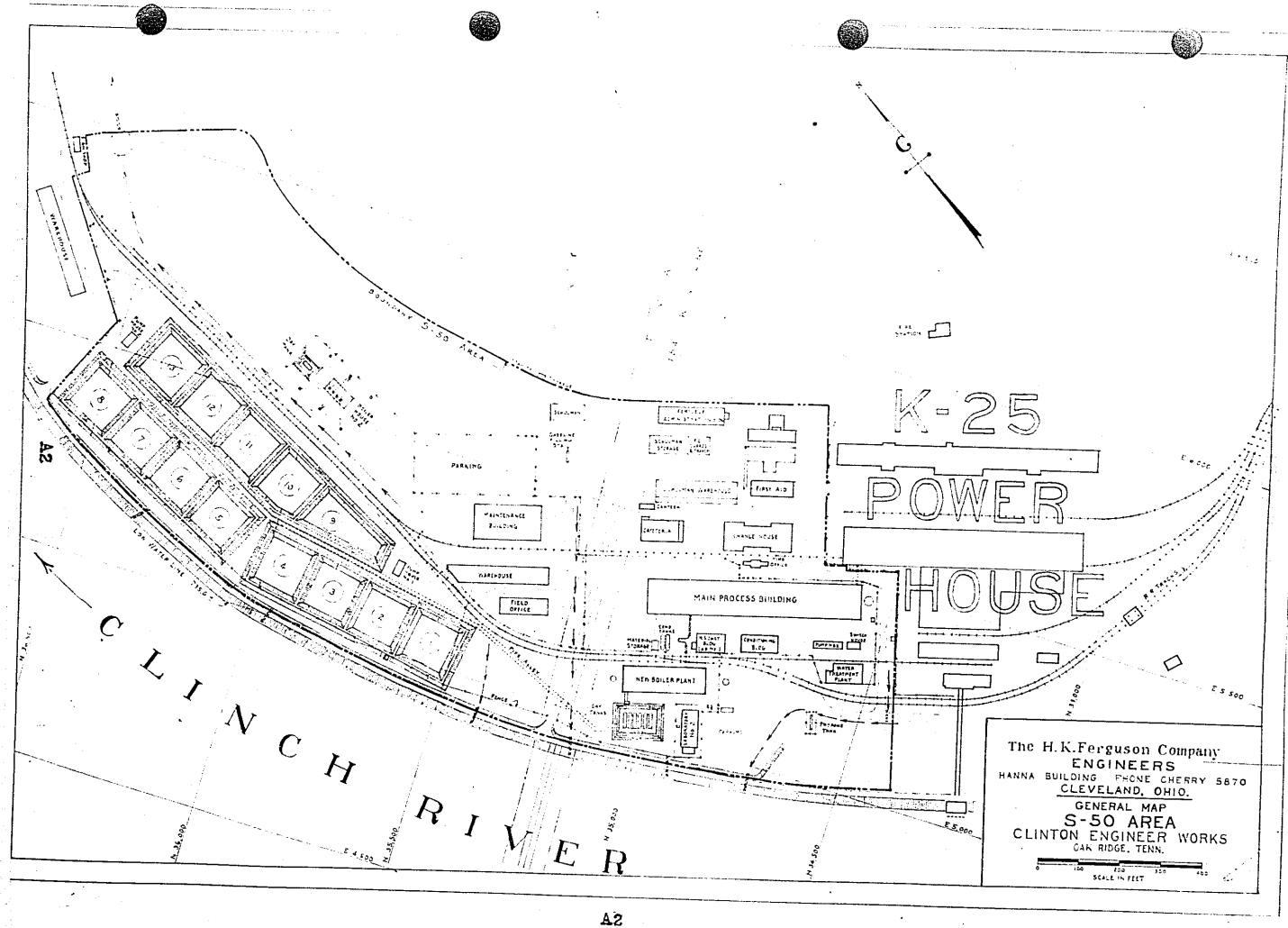
A1


K-25
POWER
HOUSE
MAIN PROCESS BUILDING
NEW BOILER PLANT
MAINTENANCE BUILDING
WAREHOUSE
FIELD OFFICE
CAFETERIA
CHANGE HOUSE
FIRST AID
PARKING
CLINCH RIVER
BOUNDARY S-50 AREA
A2
A2
The H.K.Ferguson Company
ENGINEERS
HANNA BUILDING PHONE CHERRY 5870
CLEVELAND, OHIO.
GENERAL MAP
S-50 AREA
CLINTON ENGINEER WORKS
OAK RIDGE, TENN.
SCALE IN FEET

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY

PERSONNEL
OFFICERS
ENL
P
SP
CAF
CPC
MISCL

Typical chart selected from files. Names of personnel holding positions apply as of 13 January 1945

UNIT CHIEF
M.C.FOX LT.COL., C.E.
Miss E.M. Harding CAF-4 Sect.
Responsible for entire construction and operation program in S-50.

CONSTRUCTION OFFICER
T.J.EVANS,JR. MAJ. C.E.
Lyle J. Smith, P-4 Assistant
Responsible for all construction and engineering in S-50 Area. Handling of all vouchers and administrative matters for Construction Contractors. Conducts liaison between S-50 and K-25 on steam and power requirements and construction requirements.

EXECUTIVE AND ADMINISTRATIVE OFFICER
V.S. REID CAPT. C.E.
Handling of all vouchers and administrative matters of the Operating Contractor. Handling all expediting and priorities matters. Security Officer. Handling of all matters pertaining to enlisted men in S-50.

OPERATIONS OFFICER
M.J.BARNETT CAPT. C.E.
Miss M.D. Sisk CAF-3 Sect.
Responsible for production and raw material requirements. Prepares operating reports. Handles incoming and outgoing shipments. Liaison between S-50 and other areas on technical matters. Supervises process improvement activities.

SPECIAL DUTY OFFICER
G.L.AGNOR LT. C.E.
Assigned to the Operating Contractor on special duty as directed by the Unit Chief.

OFFICE ORGANIZATION
MANHATTAN DISTRICT

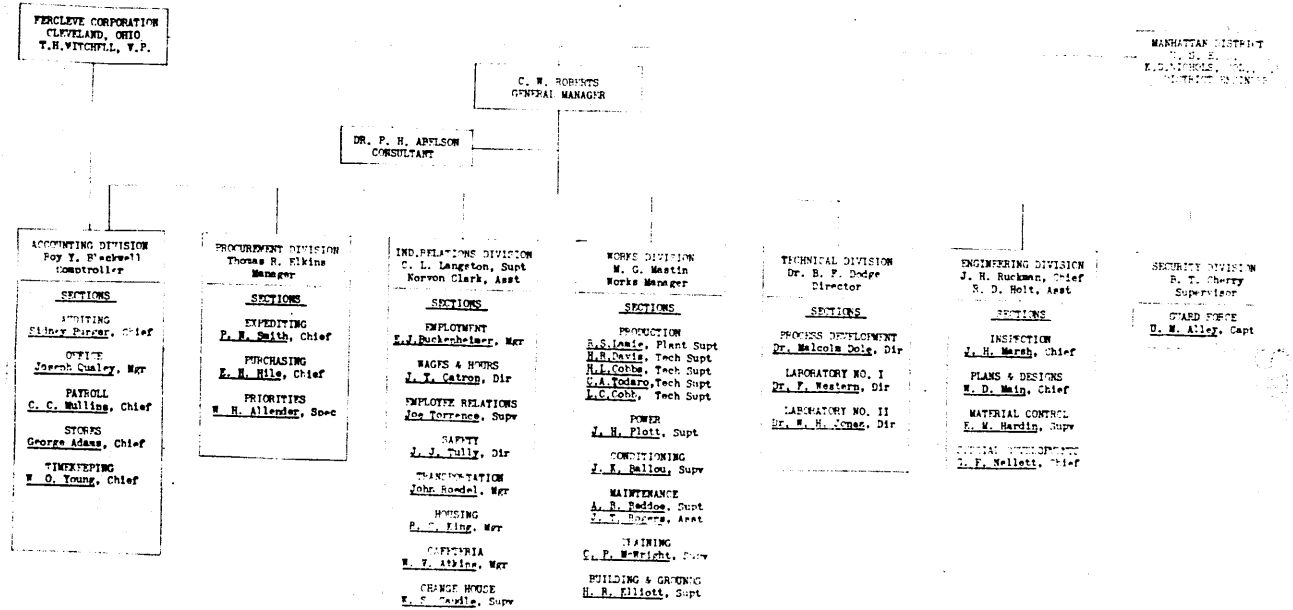
S-50 AREA
CONSTRUCTION & OPERATION

SUBMITTED [signature] APPROVED [signature] DATE 1/13/45

A-3

RESTRICTED

Manual Employees 1156
Non-Manual Employees 440
S. E. D. Personnel 116
Total 1712



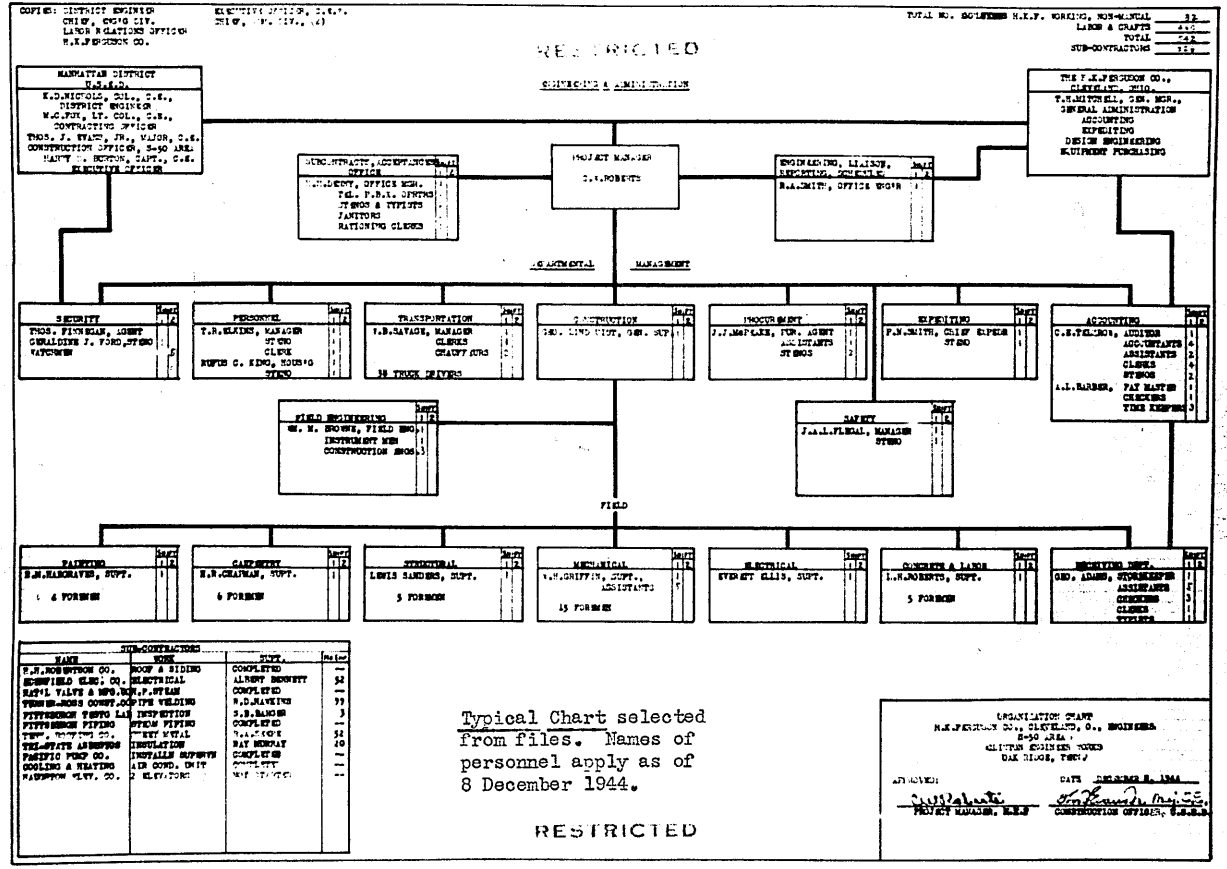
Typical Chart selected from files. Names of personnel holding positions apply as of 2 April 1945

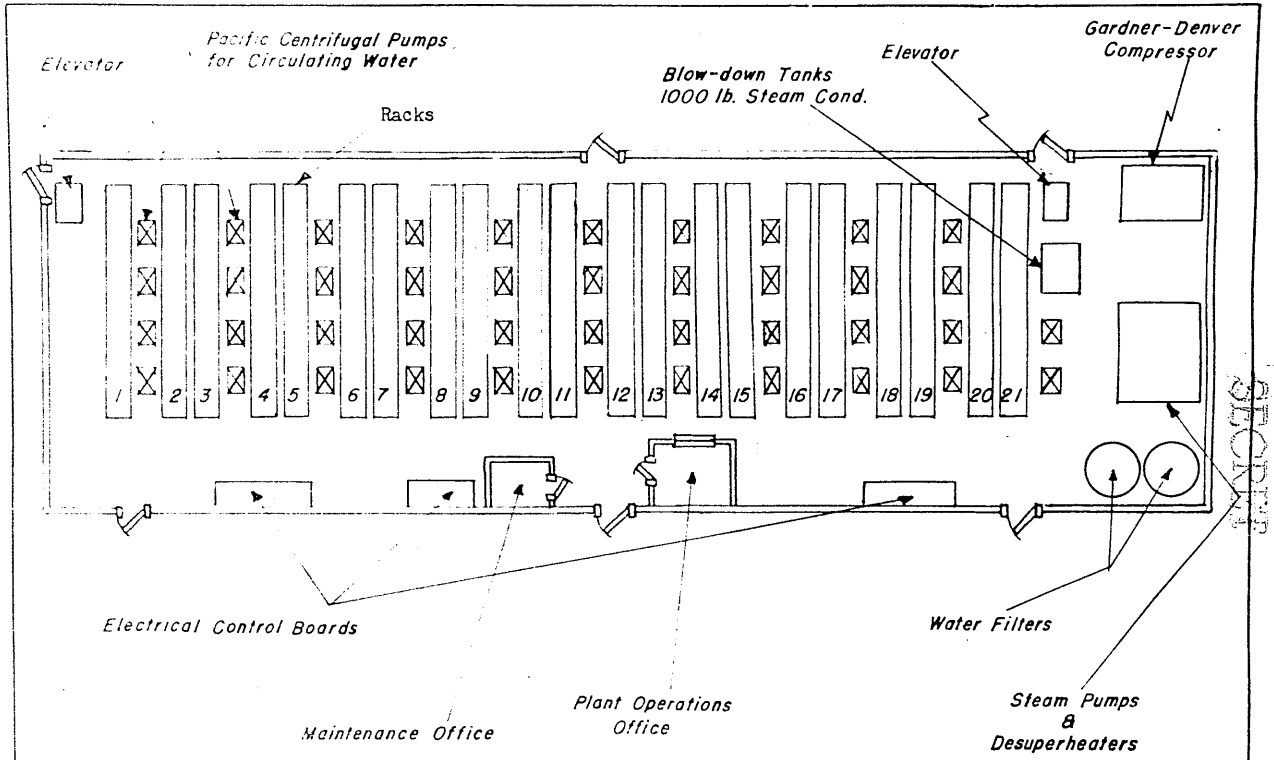
RESTRICTED

ORGANIZATION CHART
FERCLEVE CORPORATION, CLEVELAND, OHIO
OPERATORS, S-50 AREA
CONTRACT NO. W-7409-eng-100
CLINTON ENGINEER WORKS
OAK RIDGE, TENN.

APPROVED: DATE 2 April 1945

C.W.ROBERTS, GEN.MGR
FOR FERCLEVE CORP


COPIES: DISTRICT ENGINEER
CHIEF, ENGG DIV.
LABOR RELATIONS OFFICE
M.K.FERGUSON CO.
EXECUTIVE OFFICER, C.E.W.
CHIEF, ENG. DIV., (4)
TOTAL NO. EMPLOYEES M.K.F. WORKING, NON-MANUAL 32
LABOR & CRAFTS 410
TOTAL 442
SUB-CONTRACTORS 114
RESTRICTED
CONTRACTS & ADMINISTRATION
MANHATTAN DISTRICT
U.S.E.D.
K.D.NICHOLS, COL., C.E., DISTRICT ENGINEER
W.C.FOX, LT. COL., C.E., CONTRACTING OFFICER
THOS. J. EVANS, JR., MAJOR, C.E. CONSTRUCTION OFFICER, S-50 AREA
HARVEY C. BURTON, CAPT., C.E. EXECUTIVE OFFICER
THE M.K.FERGUSON CO., CLEVELAND, OHIO.
T.M.MILTON EL., GEN. MGR., GENERAL ADMINISTRATION
ACCOUNTING
EXPEDITING
DESIGN ENGINEERING
EQUIPMENT PURCHASING
SUBCONTRACTS, ACCEPTANCES & OFFICE
W.M.DOTY, OFFICE MGR.
Tel. P.B.X. OPRTRS
STENOS & TYPISTS
JANITORS
RATIONING CLERKS
PROJECT MANAGER
C.A.ROBERTS
ENGINEERING, LIAISON, EXPEDITING, CONTACTS
R.A.SMITH, OFFICE MGR
CENTRAL MANAGEMENT
SECURITY
THOS. FINNIGAN, AGENT
GERALDINE J. FORD, STENO
WATCHMEN 5
PERSONNEL
T.R.ELKINS, MANAGER
STENO
CLERK
RUFUS C. KING, HOUSING
STENO
TRANSPORTATION
T.B.SAVAGE, MANAGER
CLERKS
CHAUFFEURS
38 TRUCK DRIVERS
CONSTRUCTION
IND. ENGINEER, CHIEF SUPT.
PROCUREMENT
J.J.McCLAIN, PURCHASING AGENT
ASSISTANTS
STENOS
EXPEDITING
F.W.SMITH, CHIEF EXPEDITER
STENO
ACCOUNTING
C.E.TILDEN, AUDITOR
ACCOUNTANTS 4
ASSISTANTS 2
CLERKS 4
STENOS 2
A.L.BARBER, PAY MASTER
CHECKERS
TIME KEEPERS
FIELD ENGINEERING
W. H. BROWN, FIELD ENG.
INSTRUMENT MEN
CONSTRUCTION ENGRS.
SAFETY
J.A.L.FLEGAL, MANAGER
STENO
FIELD
PAINTING
E.M.MARGRAVE, SUPT.
4 FOREMEN
CARPENTRY
E.E.CHAMAN, SUPT.
6 FOREMEN
STRUCTURAL
LEWIS SANDERS, SUPT.
5 FOREMEN
MECHANICAL
W.M.GRIFFIN, SUPT., ASSISTANTS
15 FOREMEN
ELECTRICAL
EVERETT ELLIS, SUPT.
CONCRETE & LABOR
L.M.ROBERTS, SUPT.
5 FOREMEN
MATERIALS DEPT.
GEO. ADAMS, STOREKEEPER
ASSISTANTS
CHECKERS
CLERKS
TYPISTS
SUB-CONTRACTORS
NAME | WORK | STAT. | No Emp
E.E.ROBERTSON CO. | ROOF & SIDING | COMPLETED | —
SCHOFIELD ELEC. CO. | ELECTRICAL | ALMOST COMPLETED | 52
KATZ VALVE & MFG.CO. | P.SYSTEM | COMPLETED | —
TURNER-ROSS CONST.CO. | PIPE WELDING | N.D.MAKING | 99
PITTSBURGH TESTS LAB | INSPECTION | S.B.RANGE | 3
PITTSBURGH PIPING | STEAM PIPING | COMPLETED | —
TEW, [illegible] CO. | [illegible] METAL | [illegible] | 52
TRI-STATE ASBESTOS | INSULATION | NAT NEARLY | 10
PACIFIC PUMP CO. | INSTALLS SUPPORTS | COMPLETED | —
COOLING & HEATING | AIR COND. UNIT | [illegible] | —
HAMPTON ELEV. CO. | 2 ELEVATORS | NOT STARTED | —
Typical Chart selected from files. Names of personnel apply as of 8 December 1944.
RESTRICTED
ORGANIZATION CHART
M.K.FERGUSON CO., CLEVELAND, O., ENGINEERS
S-50 AREA
CLINTON ENGINEER WORKS
OAK RIDGE, TENN.
APPROVED: DATE DECEMBER 8, 1944
PROJECT MANAGER, K.E.D.
CONSTRUCTION OFFICER, C.E.W.A.



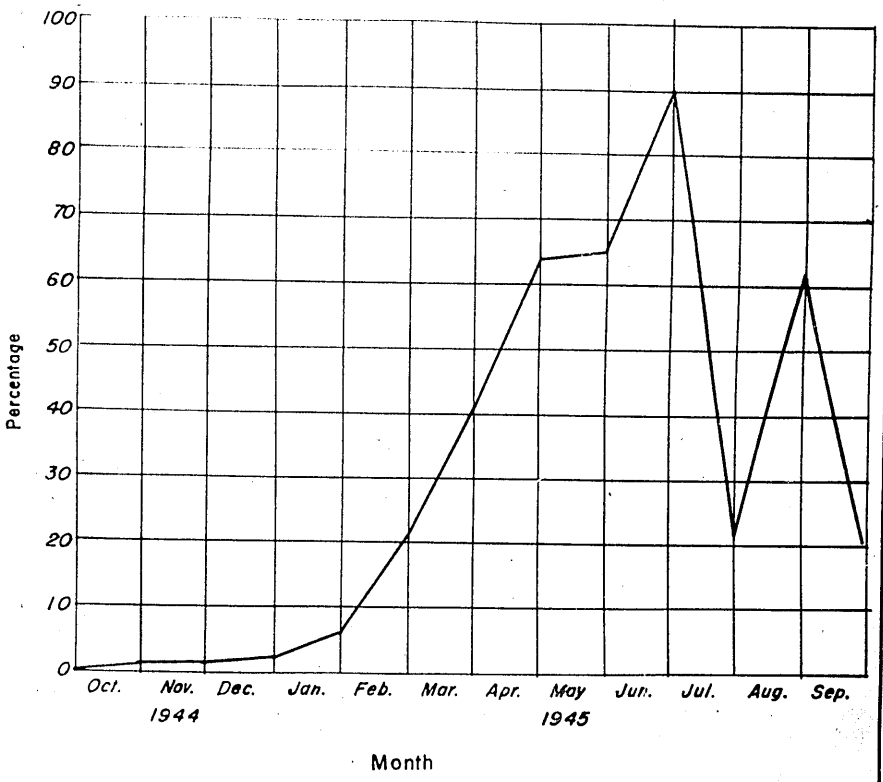
FLOOR PLAN - MAIN PROCESS BUILDING

LIQUID THERMAL DIFFUSION (S-50) PROJECT

SECRET

GRAPH SHOWING PERCENTAGE OF ORIGINAL THEORETICAL MAXIMUM OUTPUT

LIQUID THERMAL DIFFUSION (S-50) PROJECT



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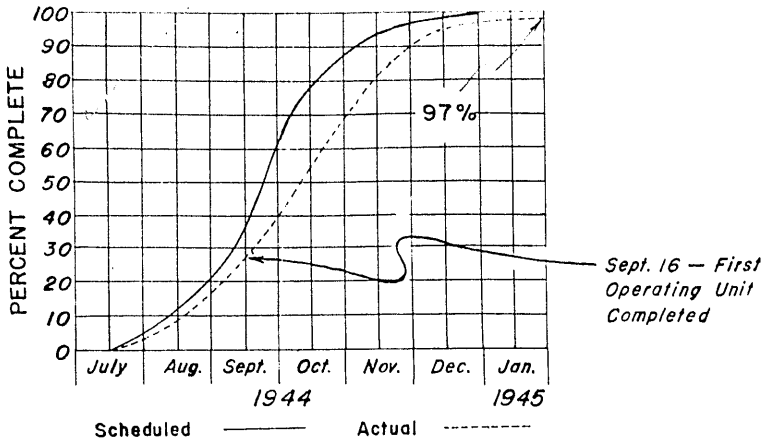
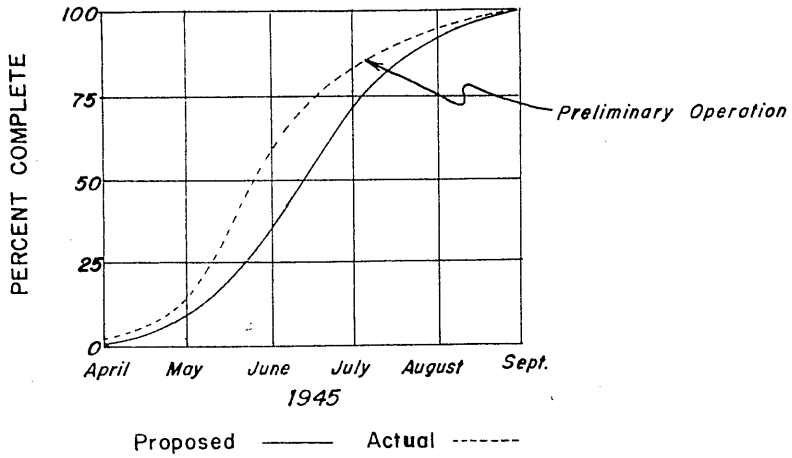
CONSTRUCTION GRAPHS

LIQUID THERMAL DIFFUSION (S-50) PROJECT

ORIGINAL CONSTRUCTION

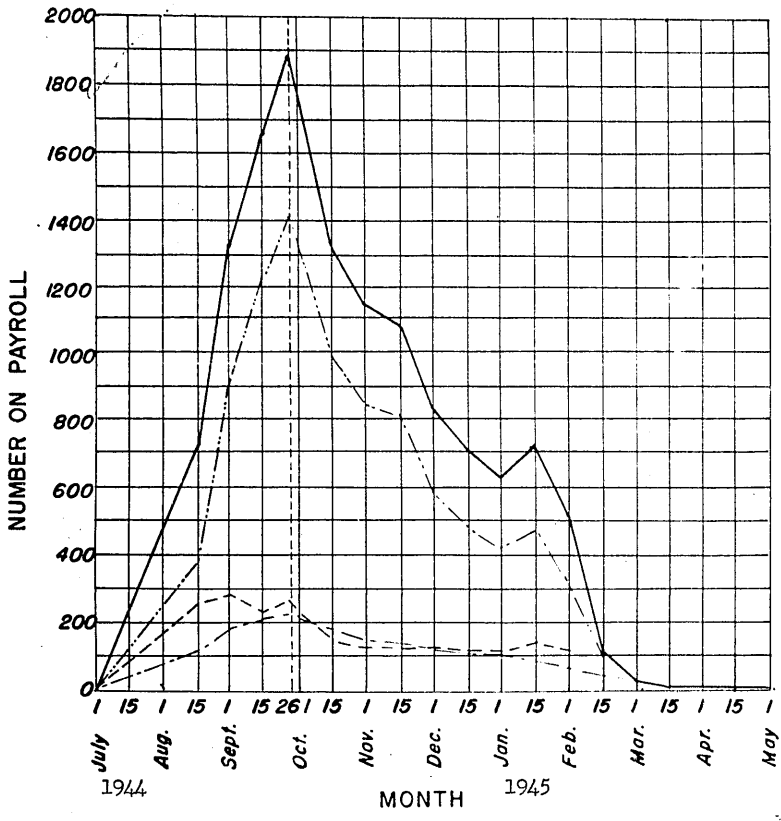


NEW BOILER PLANT



H. K. FERGUSON CO.— CLINTON ENGINEER WORKS

GRAPH
of
NUMBER ON PAYROLL



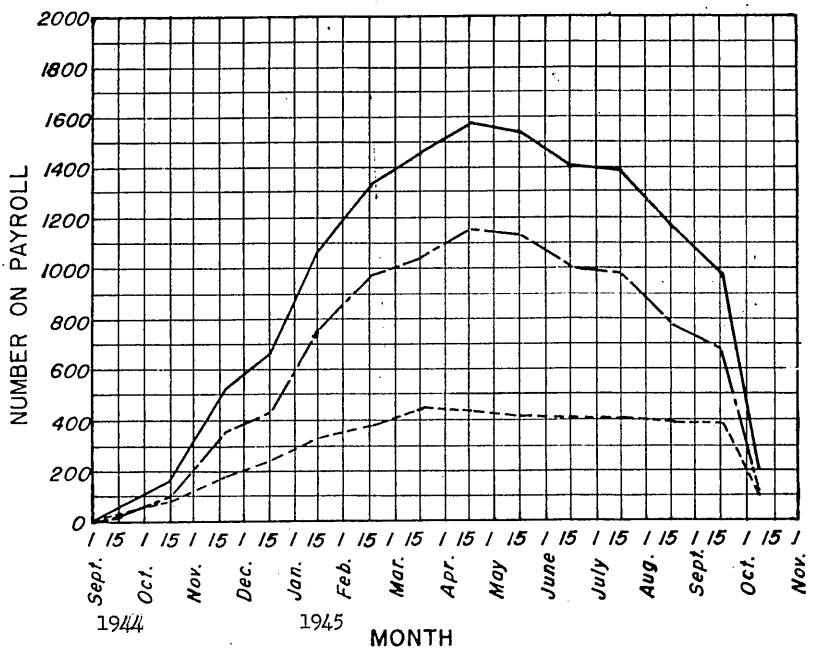
Key:

Non-Manual - - —— - - - - —— Laborers & Tenders - - - - - - - -

Crafts —·—·—·—·— Total ————————

FERCLEVE CORPORATION

GRAPH
of
NUMBER ON PAYROLL



Key:

Non-Manual ---+-------

Manual ——-——-

Total ————————

MANHATTAN DISTRICT HISTORY

BOOK VI - LIQUID THERMAL DIFFUSION (S-50) PROJECT

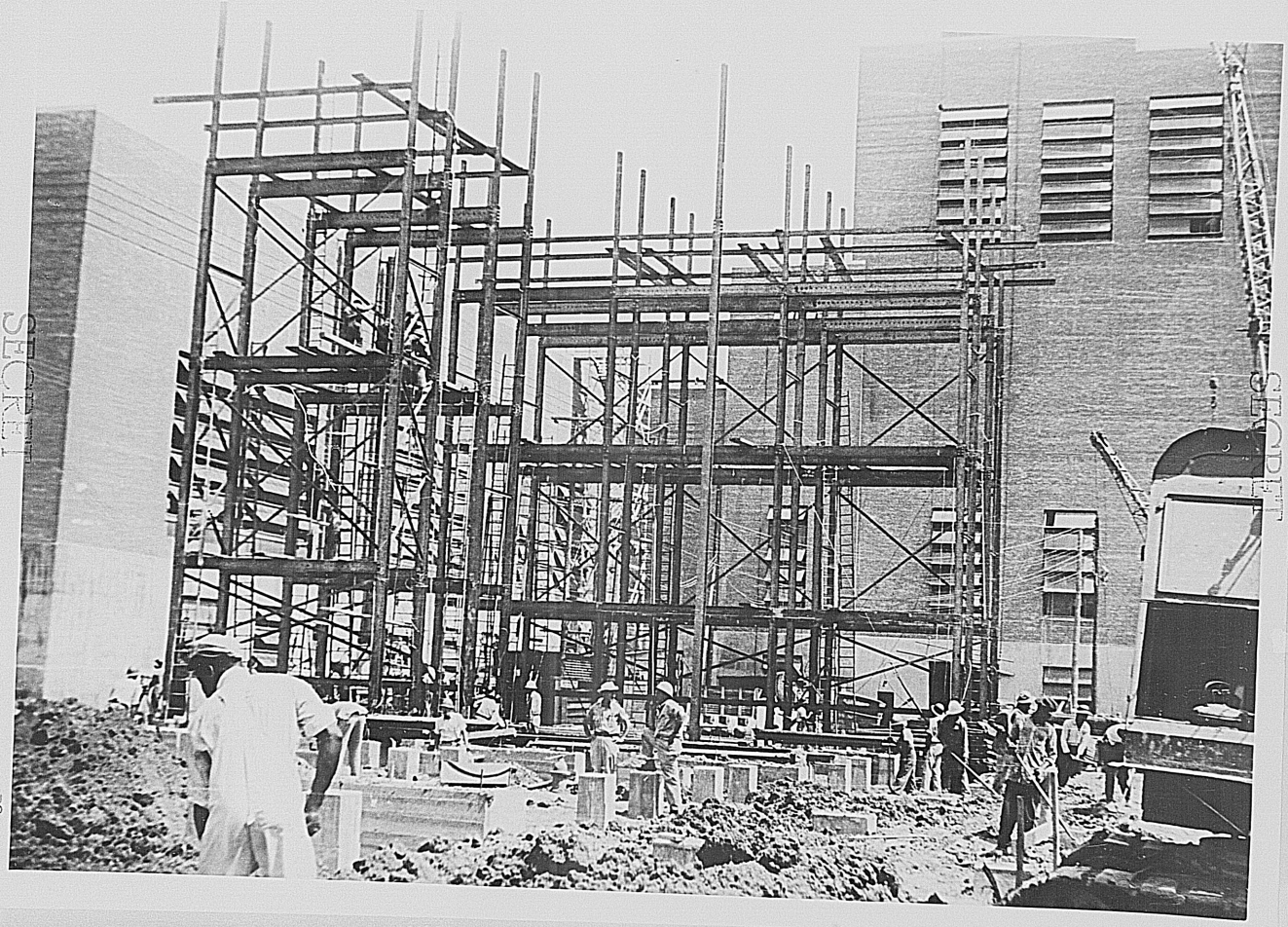
APPENDIX "B"

PHOTOGRAPHS

No.	Title
1.	Foundation Work on Main Process Building
2.	Early Work on Rack Structures in Main Process Building with K-25 Power House in background
3.	Installation of Rack Cooling Water Piping
4.	View Showing Structural Steel Framework of Main Process Building with K-25 Power House in background
5.	View of Main Process Building largely completed
6.	View of Completed Main Process Building with Switch House, Pump House, and Water Treatment Plant in foreground
7.	Panoramic View of S-50 Area showing Main Process Building, New Boiler Plant, Tank Farm, and Auxiliary Buildings
8.	View of Tank Farm showing Pipe Alley
9.	Interior of New Boiler Plant
10.	Interior of Main Process Building showing Rack, Catwalk, Mezzanine, Steam and Cooling Water Piping
11.	View of Rack from Ground Floor showing Cooling Water Pump and Piping, Elevator Shaft, Catwalk, and overhead Freeze-off Water Header
12.	Rack Crew on Catwalk at Top of Rack Changing Intercolumn Connections in Duct
13.	Operator Freezing Off Convection Line Tit

B1 Foundation Work on Main Process Building

B2 Early Work on Rack Structures in Main Process Building with K-25 Power House in background



SECRET

SECRET

B2

B3 Installation of Rack Cooling Water Piping

B4 View showing Structural Steel Framework of Main Process Building with K-25 Power House in background

B5 View of Main Process Building largely completed

B5

B6 View of Completed Main Process Building with Switch House, Pump House, and Water Treatment Plant in foreground

SECRET

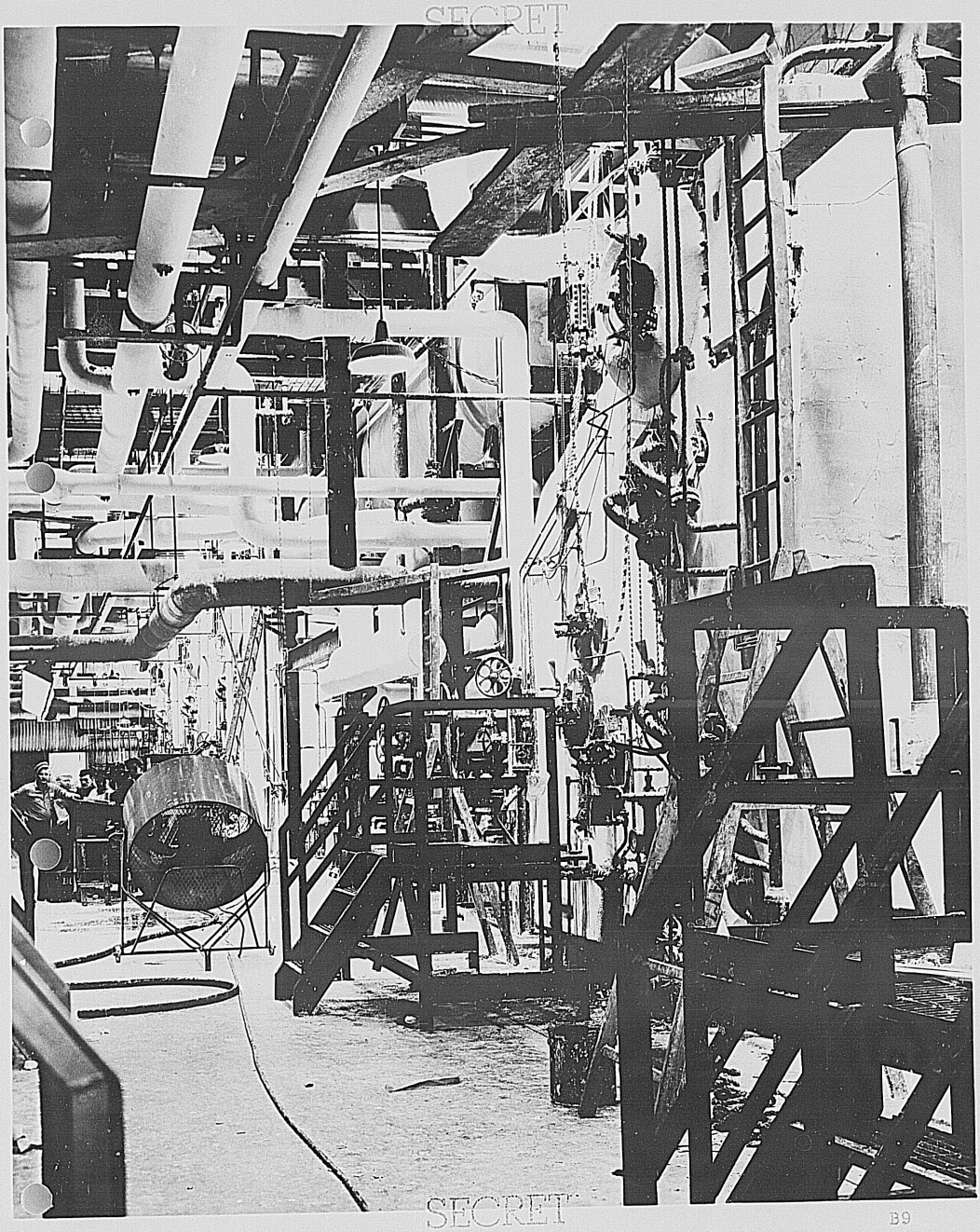
SECRET

B6

B7 Panoramic view of S-50 Area showing Main Process Building, New Boiler Plant, Tank Farm, and Auxiliary Buildings

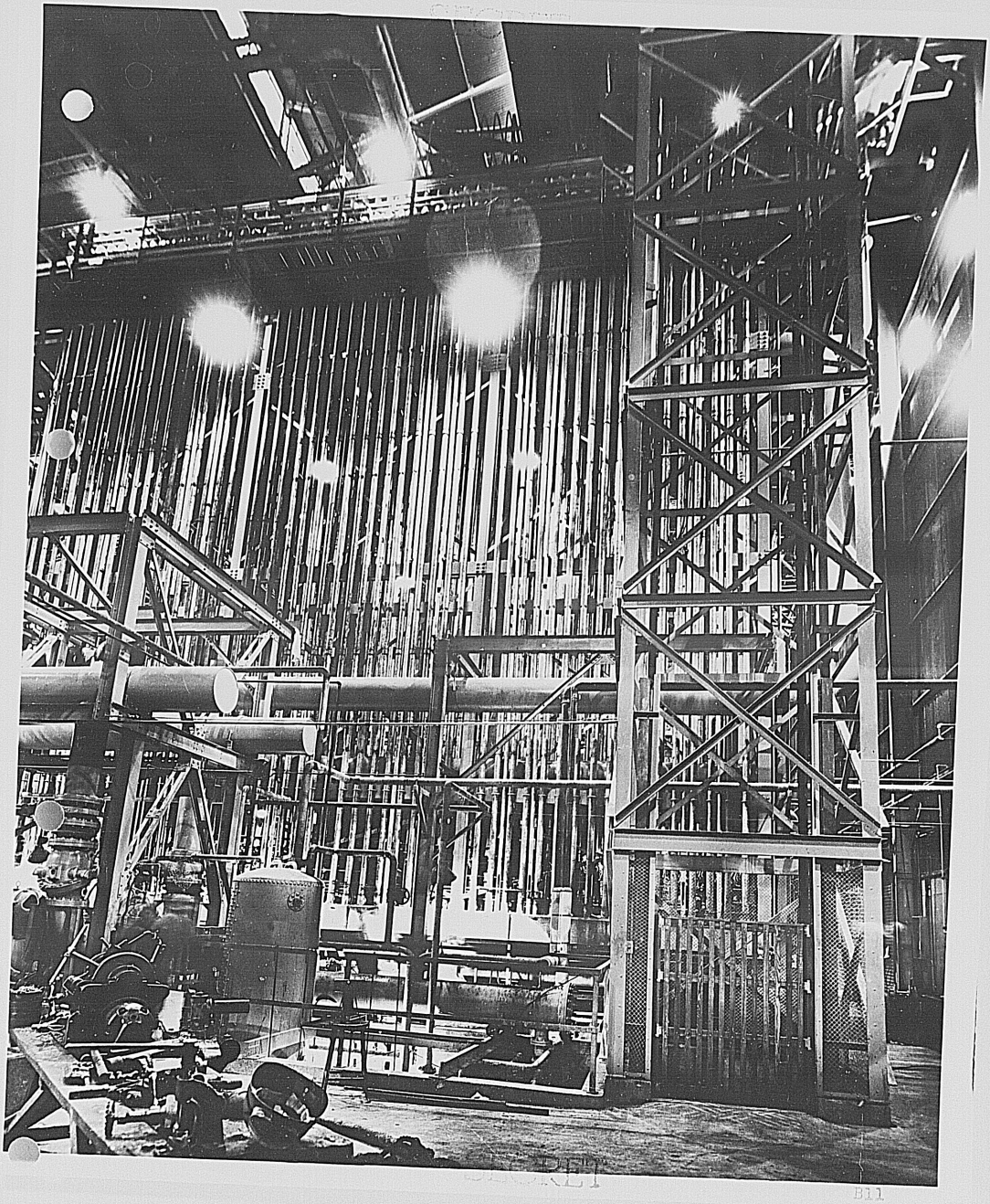
B8 View of Tank Farm showing.Pipe Alley

B9 Interior of New Boiler Plant



B10 Interior of Main Process Building showing Rack, Catwalk, Mezzanine, Steam and Cooling Water Piping

B11 View of Rack from Ground Floor showing Cooling Water Pump and Piping, Elevator Shaft, Catwalk, and overhead Freeze-off Water Header



SECRET

B11

B12 Rack Crew on Catwalk at Top of Rack Changing Intercolumn Connections in Duct

B13 Operator Freezing Off Convection Line Tit

MANHATTAN DISTRICT HISTORY

BOOK VI - LIQUID THERMAL DIFFUSION (S-50) PROJECT

APPENDIX "C"

LIST OF CONTRACTORS

No.	Title
1.-17.	Construction Contractors
18.-19.	Engineering Contractors
20.-40.	Manufacturers and Vendors
41.-42.	Operation Contractors

SECRET

S-50 CONSTRUCTION CONTRACTORS

CONSTRUCTION PRIME CONTRACTORS

NO.	CONTRACTOR	CONTRACT NO.	AMOUNT OF CONTRACT	TYPE OF CONTRACT	SCOPE OF WORK	DATE BEGUN	DATE COMPLETED
1	H. K. Ferguson Company Cleveland, Ohio (a) Original Contract (b) New Boiler Plant	W-7409-eng-23 W-22-075-eng-59	$7,590,254* 521,714*	Cost plus Fixed Fee Cost plus Fixed Fee	Architect, Engineer, Management on Original Plant. Architect, Engineer, on New Boiler Plant.	12 July 1944 26 February 1945	15 February 1946 8 August 1945
2	J. A. Jones Construction Company, Inc. Charlotte, N. C.	W-7421-eng-11	2,111,003*	Cost plus Fixed Fee	Managing Construction on New Boiler Plant.	6 March 1945	Work on New Boiler Plant and changes in K-25 P.H. being accomplished by supplemental agreement to contracts.
3	Wm. A. Pope Company Chicago, Ill.	W-7405-eng-100	666,222*	Cost plus Fixed Fee	Pipe Work, Tank Farm of New Boiler Plant.	3 May 1945	
4	A. S. Schulman Electric Company Chicago, Ill.	W-7405-eng-101	282,162*	Cost plus Fixed Fee	Electrical Work on the New Boiler Plant.	28 March 1945	
5	Grinnell Co., Inc. Providence, R. I.	W-22-075-eng-77	145,500*	Lump Sum	Pipe Work on New Boiler Plant.	18 April 1945	11 August 1945

CONSTRUCTION SUB-CONTRACTORS

6	Edenfield Electric Company Nashville, Tenn.	S. C. 201 under H.K.F. Contract in 1(a) above. Assigned to Gov't. on Feb. 12, 1945, and became Prime Contract 22-075-eng-82.	23,904*	Cost plus Fixed Fee	Labor and general supervision of all electrical work in the plant, lighting, power and communication systems for all buildings.	24 July 1944	15 March 1945
7	Turner & Ross Construction Company Houston, Texas	S. C. 202 under H.K.F. Contract in 1(a) above.	542,000	Cost plus Fixed Fee	Job fabrication and erection of all water piping. Labor for all pipe welding. Installation of certain process piping on Original Plant Construction.	11 August 1944	2 January 1945
8	H. H. Robertson Company Pittsburg, Pa.	S. C. 21 under H.K.F. Contract in 1(a) above.	78,146	Lump Sum	Fabrication and Erection of ventilators and siding for Main Process Building, Pump House, and Water Treatment Plant.	14 August 1944	30 December 1944 (Final Acceptance)
9	Pittsburg Piping and Equipment Company Pittsburgh, Pa.	S. C. 78 under H.K.F. Contract in 1(a) above.	97,806	Lump Sum	Fabrication and erection of all high pressure condensate piping including shop detailing on Original Plant Constr.	12 September 1944	5 February 1945 (Final Acceptance)
10	National Valve & Manufacturing Company Pittsburgh, Pa.	S. C. 52 under H.K.F. Contract in 1(a) above.	98,429	Lump Sum	Fabrication and erection of all high pressure condensate piping, including shop detailing on Original Plant Construction.	28 August 1944	28 November 1944 (Final Acceptance)
11	Tennessee Roofing Company Knoxville, Tenn.	S. C. 405 under H.K.F. Contract in 1(a) above.	273,385	Lump Sum	Fabrication and erection of all sheet metal process ducts, building flashing, exhaust hood and other miscellaneous sheet metal parts for Original Plant.	10 August 1944	10 February 1945 (Final Acceptance)
12	Cooling and Heating Company, Inc. Youngstown, Ohio	S. C. 167 under H.K.F. Contract in 1(a) above.	4,431	Lump Sum	Supply and erection of laboratories air-conditioning units.	22 September 1944	1 December 1944
13	Tri-States Asbestos Company Knoxville, Tenn.	S. C. 215 under H.K.F. Contract in 1(a) above. Assigned to Gov't. on Feb. 16, 1945, and became Prime Contract 22-075-eng-83	20,494*	Lump Sum	Insulation of all steam condensate water, and process piping in Original Plant Construction.	28 August 1944	15 March 1945
14	Pittsburg Testing Laboratories Pittsburgh, Pa.	S. C. 87 under H.K.F. Contract in 1(a) above.	87,500	Unit Price	Inspection and testing of all high pressure welding and qualifying of welders on Original Plant Construction.	1 September 1944	31 January 1945
15	Houghton Elevator Company Toledo, Ohio	S. C. 1295 under H.K.F. Contract in 1(a) above.	9,545	Unit Price	Fabrication and erection of two freight and passenger elevators in Main Process Building.	22 December 1944	24 January 1945
16	Consolidated Chimney Company Chicago, Ill.	S. C. 66 under J. A. Jones Constr. Company Prime Contract W-7421-eng-11 in 2 above.	15,040	Lump Sum	Two radial brick chimneys for New Boiler Plant.	8 May 1945	6 June 1945
17	Asbestos-Magnesia Company Chicago, Ill	S. C. 66 under J. A. Jones Constr. Company Prime Contract W-7421-eng-11 in 2 above.	78,230	Lump Sum	New Boiler Plant Insulation.	11 June 1945	Canceled 4 September 1945.

* This list of prime contract costs does not serve as an estimation of total overall construction costs attributable to the S-50 Project (See App. D6) because it includes only those important construction contractors actively engaged in the S-50 Project, and does not include all those contractors who did construction work in the K-25 Power House whose cost was attributed to S-50.

SECRET

No.	Contractor	Scope of Work
	Engineering Contractors	
18.	The Babcock and Wilcox Company Barberton, Ohio	Supervision and consultation for New Boiler Plant
19.	The Kellex Corporation New York, N.Y.	A subsidiary of M. W. Kellogg Company. Architect-Engineer services for New Boiler Plant
	Manufacturers and Vendors	
20.	The Bailey Meter Company Cleveland, Ohio	Flowmeters and controls
21.	The Calumet-Hecla Copper Company, Wolverine Tube Division, Detroit, Michigan	Copper column tubing
22.	The Chapman Valve Manufacturing Company, Indian Orchard, Mass.	Steam valves
23.	The Cochran Company Philadelphia, Pa.	Deaerators for New Boiler Plant
24.	The B. F. Goodrich Company Akron, Ohio	Special rubber hose for process
25.	Grinnell Company Providence, R.I.	Process columns
26.	The Griscom-Russell Company New York, N.Y.	Oil heaters and evaporator for New Boiler Plant
27.	Ingalls Iron Works Birmingham, Ala.	Structural Steel for Main Process Building
28.	The International Nickel Company, Huntington, W. Va.	Nickel column tubing
29.	Kewanee Boiler Corporation Kewanee, Ill.	Small boilers for Tank Farm
30.	The Mehring and Hanson Company, Washington, D.C.	Process columns
31.	Noland and Company Cleveland, Ohio	Column pipe and fittings

No.	Contractor	Scope of Work
32.	Pacific Pumps, Inc. Huntington Park, Cal.	Cooling water and desuper-heating pumps
33.	The Revere Copper and Brass Company, Cleveland, Ohio	Copper column tubing
34.	Struthers Wells Corporation Warren, Pa.	Heat exchangers
35.	The B. F. Sturtevant Company, Boston, Mass.	Turbo-blowers
36.	The Swartwout Company Cleveland, Ohio	High pressure steam specialty items
37.	Westinghouse Electric and Manufacturing Corporation Pittsburgh, Pa.	Electric motors and turbo-blowers
38.	Williams and Company, Inc. Cleveland, Ohio	Nickel tubing
39.	Worthington Pump Machinery Company, Harrison, N.J.	Pumps and compressors
40.	Youngstown Welding and Engineering Company Youngstown, Ohio	Nickel pressure vessels

Operation Contractors

41.	Carbide and Carbon Chemicals Corporation, Oak Ridge, Tenn.	A subsidiary of Union Carbide and Carbon Corporation. Operation of K-25 Power House. (See Book II, Vol.5)
42.	The Fercleve Corporation Cleveland, Ohio	A subsidiary of the H. K. Ferguson Company. Operation of the S-50 Plant

MANHATTAN DISTRICT HISTORY

BOOK VI - LIQUID THERMAL DIFFUSION (S-50) PROJECT

APPENDIX "D"

DOCUMENTS

No.	
1.	Letter concerning 26 June 1944 Washington Meeting (from Lt. Col. M. C. Fox to Major H. S. Traynor - 16 September 1944)
2.	Memorandum on Completion Schedule (from Major General L. R. Groves to Lt. Col. M. C. Fox - 4 July 1944)
3.	Letter on Specifications (from Col. K. D. Nichols to Ferclève Corporation - 1 July 1944)
4.	Letter on Proposed New Boiler Plant (from P. H. Abelson to C. W. Roberts - 16 February 1945)
5.	Memorandum on Operations Costs (from L. Martinelli to Lt. Col. H. R. Fraser - 7 June 1946)
6.	Memorandum on Construction Costs (from L. Martinelli to Lt. Col. H. R. Fraser - 31 May 1946)
7.	Letter concerning Termination of Operations (from Col. E. H. Marsden to Major T. J. Evans, Jr. - 4 September 1945)
8.	Memorandum concerning Safety Record (from J. R. Maddy to Major T. J. Evans, Jr. - 30 October 1945)

ARMY SERVICE FORCES
UNITED STATES ENGINEER OFFICE
MANHATTAN DISTRICT
OAK RIDGE, TENNESSEE

IN REPLY
REFER TO EIDMB

16 September 1944.

Memo To: H. S. Traynor, Major, C.E.

A meeting, attended by the following, was held in Major General L. R. Grove's office, Washington, D. C., Monday morning, 26 June 1944:

Major General Groves
Lt. Colonel Fox
Dr. Tolman
Mr. W. N. Thompson

The H. K. Ferguson Company had been selected by General Groves as the contractor on the basis that it was believed this company would make the most over-all effort to get the job done in the prescribed length of time.

After discussing availability of personnel with Mr. Thompson, chief engineer of The H. K. Ferguson Company, we went to the Naval Research Laboratory, Anacostia, where we met Admiral Van Kueran, Dr. Gunn, Dr. Abelson and Commander Gibbs, wherein procedures were worked out which would enable the Navy to turn over certain information to the Army. Drs. Gunn and Abelson are the inventors of the process and are employees of the U. S. Navy. At a previous meeting which had been held, Admiral King had instructed the people to cooperate with General Grove's organization so that the pilot plant could be enlarged upon and put on a production basis. At the 26 June meeting, everyone was in accord that immediate action should be taken to proceed with construction.

Subsequent to this meeting, Dr. Abelson, Mr. Thompson and myself went to Philadelphia, arriving there about 4:00 P.M. We met Captain Bonvillian, commanding officer of the Naval Boiler and Research Laboratory, in the U. S. Navy Yard, Philadelphia, and inspected the plant. The boilers were under construction and Dr. Abelson had about 100 columns fabricated which he expected to put into service on 15 July 1944.

Dr. Abelson gave us copies of Navy drawings which indicated the construction of the steel unit supports and the columns themselves.

M. C. FOX,
Lt. Col., Corps of Engineers.

D 1

SAVE WASTE CONSERVATION

CONFIDENTIAL

WAR DEPARTMENT
P. O. Box 2610
WASHINGTON, D. C.

REFER TO FILE No. _____

SECRET

4 July 1944

RECEIVED JUL 7 - 44 AM

RECEIVED CLASSIFIED FILE U. S. ENGINEER OFFICE MANHATTAN DISTRICT

FOR VICTORY BUY UNITED STATES WAR SAVINGS BONDS AND STAMPS

Subject: Completion Schedule. 41960

To: Lt. Colonel Mark C. Fox, P. O. Box E, Oak Ridge, Tennessee.

After considering the various factors involved, I feel that my statement to you as to the schedule of completion of the work under your charge was reasonable, namely 75 days for the first units to be in operation, with all units in operation in 90 days. That means 75 days will be up on 15 September and 90 days on 30 September. I think you can beat it.

L. R. GROVES,
Major General, C. E.

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IN REPLY REFER TO EIDNA

ARMY SERVICE FORCES
UNITED STATES ENGINEER OFFICE
MANHATTAN DISTRICT
OAK RIDGE, TENNESSEE

1 July 1944

Fercleve Corporation,
P. O. Box 1265,
Oak Ridge, Tennessee

Gentlemen:

In accordance with paragraph 3, Article IV of Fercleve Corporation Contract W-7409-eng-100, of which this letter is a part, the following methods of operation for the S-50 plant and the specifications for the product are set forth.

The Contractor will exert every effort to provide all personnel, equipment and services to operate the plant at maximum capacity unless otherwise directed in writing by the Contracting Officer or his authorized representative. The plant consists of a number of refluxer columns grouped in sets designated as racks which are to be operated in accordance with procedures established by Dr. Phillip H. Abelson and altered from time to time with his concurrence.

During the initial phase of operations, each rack, as it is brought into service, will be operated as a separate unit, with no stripping of the off-gas and no rectification of the product. Feed will be supplied to the plant by the Contracting Officer at a concentration of approximately 0.714 per cent. Under these conditions it is anticipated that the product concentration will be about 126 per cent of normal material and the off-gas about 95 per cent of normal. The specifications of this type of operation are:

a. Minimum concentration of product to be 120 per cent of normal material. No product of lower concentration will be shipped without specific authorization in writing by the Contracting Officer.

b. No limit is set for the maximum concentration of the product since this will depend upon the method of operation and upon operating characteristics which are as yet undetermined. However, if, in the opinion of the Contracting Officer the product concentration is higher than required, he may

direct in writing, that the concentration be reduced, in order to produce a greater quantity of lower concentration product.

c. The concentration of the off-gas will be in the range 94 per cent to 95 per cent of normal. No definite minimum or maximum limits are established since operating conditions may at this time dictate the optimum concentration. All off-gas in this concentration range will be stored and will, at some date specified by the Contracting Officer, be stripped to approximately 84 per cent of normal.

d. Analysis for isotopic concentration will be performed in the S-50 Area by one or both of the following methods.

(1) Mass spectrometer
(2) Alpha counting

In the event that results from either source are less than the minimum concentration of 120 per cent of normal, the matter will be referred to the Contracting Officer for decision as to disposition of the material.

e. No specifications are established for impurities. C-616 is supplied to the S-50 Area with only negligible amounts of contaminants and because of the nature of the S-50 process, it is assumed that these impurities will not be increased appreciably in the final product. However, if, in the opinion of the Using Agency, impurities are present in amounts sufficient to affect its use, the Contracting Officer may require the Contractor to purify the material, if this appears practicable, or he may direct that it be discarded.

Operation of the S-50 plant under conditions other than those specified above may be set forth in writing by the Contracting Officer, or his authorized representative, from time to time. For example, it may prove desirable to produce material of concentration higher than 126 per cent of normal by operating columns in series. Similarly it may become necessary to strip off-gas initially to some concentration lower than 95 per cent of normal. It is expected that such a manner as to achieve the results specified by the Contracting Officer, or his authorized representative.

direct in writing, that the concentration be reduced, in order to produce a greater quantity of lower concentration product.

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Operation of the S-50 plant under conditions other than those specified above may be set forth in writing by the Contracting Officer, or his authorized representative, from time to time. For example, it may prove desirable to produce material of concentration higher than 126 per cent of normal by operating columns in series. Similarly it may become necessary to strip off-gas initially to some concentration lower than 95 per cent of normal. It is expected that such a manner as to achieve the results specified by the Contracting Officer, or his authorized representative.

Fercleve Corporation 1 July 1944

The pound is established as the official unit for reporting production quantities.

The Contractor assumes accountability for all U-616, both feed and product, while it is in the S-50 Area.

It is requested that the original copy of this letter be signed and returned to this office as evidence of the acceptance of the statements contained herein.

Very truly yours,

K. D. NICHOLS,
Colonel, Corps of Engineers,
District Engineer.

Accepted:

Fercleve Corporation

Date: _____

16 February 1945.

SECRET

Kellex Corporation,
Clinton Engineer Works,
Oak Ridge, Tennessee.

Attention: Mr. C. W. Roberts.

Dear Sir:

I have looked over the proposal which involves operation of a part of the S-50 plant at 450 pound saturated steam pressure. The proposal appears to be a sound one. Theoretically the operation of this plant at about 450 pound steam pressure would result in a steam consumption of approximately 70% of the steam consumption under present operating conditions in pounds per hour. Process-wise, production should be something in the order of 50% of the theoretical production using 1000 pound steam. However, in view of the expected reduction in operating difficulties, it is entirely proper to assume that ultimate mean daily production will approach that of an operation which uses 1000 pound steam.

Yours very truly,

Philip H. Abelson

PHILIP H. ABELSON.

SECRET

CONFIDENTIAL

This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, 50 U. S. C. 31 and 32, as amended. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

SAVE

Cook
Archer
2 Gritzner
2 Haigerty

IN REPLY REFER TO EIDMV-10

Mail & Rec.

RESTRICTED

ARMY SERVICE FORCES
UNITED STATES ENGINEER OFFICE
MANHATTAN DISTRICT
OAK RIDGE, TENNESSEE

SECRET

7 June 1946.

Subject: Revised Estimate of Expenditures - Fercleve Corp.

MEMORANDUM to Lt. Col. Harvey R. Fraser, Spec. Asst. to Operations Officer, K-25.

In accordance with request of Mr. Haigerty there is scheduled below revised summary of expenditures in connection with contract with Fercleves Corporation No. W7409-eng-100.

It is to be noted that the Fercleve Corp has included the value of Army - Navy labor on an estimated basis as a cost of operation. While this serves to reflect true costs, it does not represent actual expenditures to the District, and this office has not been inclding such costs in similar reports.

It is also to be noted that the value of steam and electricity furnished by the K-25 Power House has been included as an operating cost on an estimated basis, although no formal billings have been made.

Fercleve Corporation (S-50 Area)
Statement of Expenditure - 1 June 1946
Costs Incurred under Contract with Fercleve Corp. W7409-eng-100.

Materials & Expense	1,508,570	
Payrolls	3,126,355	
Fee	127,000	
Termination Cost	42,877*	
Total Fercleve Cost		4,804,802
Government Furnished Items:		
Mat'ls., oil, steam & elec.	1,834,296	
Labor by other Contractors	152,596	
Army - Navy Labor	200,922	
Total Government Costs		2,187,814
Total Operating Costs		6,992,616

*Contract termination settlement agreed upon, but not as yet paid.

RESTRICTED

L. MARTINELLI,
Chief, Cost Section.

SECRET

D5

Subject: S-50 Construction Costs. SECRET 31 May 1946

MEMORANDUM to Lt. Col. Harvey R. Fraser.

(Attention: Leo Haigerty.)

1. Listed below are estimated costs applicable to Area S-50 Construction program as of 1 June 1946. Final cost figures are not as yet available.

2. It is to be noted that the Costs shown under Sections 750 and 760 covers construction in the K-25 area but are attributable to the S-50 Area.

Area S-50 - Proper

Main Process Building	
New Boiler Plant	
Tank Farm Auxiliary Boiler House	
Water Treatment Plant	
Laboratory Buildings	
Tank Farm	
Condensate Tanks	
Water Supply & Distribution	
Auxiliary Misc., Buildings	
Pipe Lines - Steam - Oil, etc.,	
Fencing - Drainage, etc.,	
Total	$11,263,112

Section 750 (Physically located in Area K-25 but directly applicable to Area S-50).

Addition to Boiler Room in K-25 Power Plant including necessary Inside and Outside lines and utilities.

Total $ 1,124,175

Section 760 (Physically located in Area - K-25 but directly applicable to Area S-50.

Evaporator plant in K-25 Power Plant including necessary lines and utilities. 523,352

Total $12,910,639

Grand Total Costs - Area S-50

L. MARTINELLI,
Chief Cost Section.

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ARMY SERVICE FORCES
UNITED STATES ENGINEER OFFICE
MANHATTAN DISTRICT
OAK RIDGE, TENNESSEE

IN REPLY REFER TO EIDMC-5 HD 600.18

4 September 1945.

Subject: Operations at S-50.

To: Major T. J. Evans, Officer-in-Charge, S-50.

1. Confirming recent instructions, steps will be initiated by you this date to discontinue operation of the S-50 plant at once and place the plant in standby condition for possible future operation.

2. In order that this office may be kept advised of progress in executing this plan, it is desired that the following information be submitted:

a. Copies of notifications and letters of instruction to principal contractors directing the discontinuance of operations and authorizing the undertaking of work necessary to place the plant in a standby condition.

b. The schedule for executing the plan and completing demobilization of S-50 forces. It is desired that this schedule be submitted by 8 September 1945.

c. Tabulation of contracts which will be terminated as a result of discontinuing the operations of this plant, together with effective date of termination, schedule for negotiating final settlements and other pertinent data. It is desired that this schedule be submitted by 8 September 1945.

3. A short summary report reflecting general progress in effecting the plan for shutdown and placing the plant in standby condition will be submitted on Monday of each week. Data requested in sub-paragraphs b and c above will be brought up to date every two weeks and submitted with alternate weekly reports commencing 17 September 1945.

For the District Engineer:

E. H. MARSDEN,
Colonel, Corps of Engineers,
Executive Officer.

SECRET

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ARMY SERVICE FORCES
UNITED STATES ENGINEER OFFICE
MANHATTAN DISTRICT
OAK RIDGE, TENNESSEE

IN REPLY REFER TO: ID.Mgl.

3 October 1945.

Subject: Overall Injury Rates for S-50 Area Contractors.

MEMORANDUM to Major T. J. Evans, S-50 Unit Chief.

In compliance with your request for overall injury rates for S-50 Area contractors along with injury rates for Clinton Engineer Works for the same periods of time, the following rates are submitted:

Construction	*Frequency Rate	**Severity Rate
H. K. Ferguson Co. (July 1944 thru March 1945)	2.92	.08
Edenfield Electric Co. (February and March 1945)	44.45	.31
Tri-State Asbestos Co. (February and March 1945)	5.00	0.00
Clinton Engineer Works (July 1944 thru March 1945)	5.50	1.34
National Average for Construction, 1944 (U. S. Dept. of Labor)	27.70	2.38
Operations		
Feroleve Corporation (Sept. 1944 thru Sept. 1945)	13.36	0.38
Clinton Engineer Works (Sept. 1944 thru Aug. 1945)	7.41	0.74
National Average for Manufacturing, 1944 (U. S. Dept. of Labor)	18.40	1.07

* Frequency rate - number of lost-time injuries per million man-hours of exposure.

** Severity rate - number of days lost per 1000 man-hours of exposure.

James R. Nobbe
JAMES R. NOBBE,
District Safety Engineer.

MANHATTAN DISTRICT HISTORY

BOOK VI - LIQUID THERMAL DIFFUSION (S-50) PROJECT

APPENDIX "E"

TABULATIONS

No.

1. List of Buildings and Descriptions

2. List of Wages of Construction Workers

LIST OF BUILDINGS AND DESCRIPTIONS

Administration Building - office building of wood construction, about 159 feet long by 40 feet wide by 15 feet high.

Auxiliary Pump Houses (2) - 18'11" wide, 36'6" long, and about 12' high with concrete block walls, concrete floor and roof slab, each housing four Worthington rotary oil pumps.

Boiler Plant No. 2 - 33'2" wide by 72'6" long by about 25' high, with concrete block walls, structural steel roof framing, corrugated iron roofing and concrete floor, housed four Kewanee boilers.

Cafeteria - about 92 by 50 by 20 feet, of wood construction, with concrete floor slab and asphalt tile floor covering, acoustical ceiling, and seating capacity of 120.

Canteen - small building of wood construction about 12 by 36 by 10 feet.

Change House - about 175 by 68 by 15 feet, of wood construction, with concrete floor, showers, and locker facilities.

First Aid Building - produced by remodelling an existing temporary wooden building, about 105 by 37 by 14 feet.

Gasoline Filling Station - small, two-pump facility of wood construction.

Laboratory No. 1 - about 75 by 45 by 15 feet, of wood construction, with concrete floor, housing mass spectrometer equipment.

Laboratory No. 2 - about 65 by 40 by 15 feet, of wood construction, housing alpha-counting equipment.

Machine Shop - about 162 by 84 by 25 feet, with concrete foundation and floor, concrete block walls, structural steel roof framing, and corrugated asbestos-cement roof.

Material and Conditioning Shop - 100 by 40 by 15 feet, of wood construction, containing office, conditioning shop, clerk's storeroom, gauge shop, salvage shop, nickel shop, and testing and inspection shop.

New Boiler Plant - 55 feet 9 inches wide by 199 feet 8 inches long by about 40 feet high, with concrete floor, structural steel frame, corrugated transite sides, corrugated iron roof, containing a feedwater control laboratory and operating office. The building housed twelve remodelled destroyer-escort boilers, and was provided with two brick chimneys.

Pump House - 75 feet by 16 feet by 14 feet, built over a concrete pump-well reservoir 21 feet deep, with structural steel frame, sides of corrugated Robertson protected metal, tar and gravel roof on gypsum plank, housing four 36-inch 15,000 GPM make-up water pumps.

Storage Shed - 24 feet by 20 feet by 15 feet, with wooden frame and corrugated asbestos-cement siding and roof, for storing raw material.

Switch House - about 15 feet by 42 feet by 12 feet, of brick and concrete construction, housing electrical switchboard and transformer panel.

Time Office and Clock Alley - small wooden building.

Water Treatment Plant - about 73 feet by 48 feet by 20 feet, with concrete foundation and tanks, structural steel frame, sides and roof of Robertson protected metal, housing pumps, tanks, feeders, and other equipment for treatment of freeze-off water.

LIST OF WAGES OF CONSTRUCTION WORKERS

Type of Worker	Wage per Hour
Air tool operator (jackhammerman, vibrator)	$ 0.75
Asbestos workers	1.50
Asbestos workers improvers;	
1st year	.75
2nd year	1.00
3rd year	1.25
4th year	1.25
Asphalt shovelers	.625
Asphalt rakers	.625
Blacksmiths	1.375
Balcksmith's helpers	.775
Blasters, powdermen	1.00
Boilermakers	1.50
Boilermaker's helpers	1.25
Bricklayers	1.625
Bricklayer's helpers, apprentices:	
1 st year	.65
2nd year	.80
3rd year	.95
4th year	1.10
Carpenters, journeymen	1.25
Carpenter's apprentices:	
1st year	.65
2nd year	.80
3rd year	.95
4th year	1.10
Cement finishers	1.375
Electricians	1.50
Electrician's apprentices:	
1st year	.65
2nd year	.80
3rd year	.95
4th year	1.10
Firemen	.90
Gas and Diesel mechanics	1.50
Gas and Diesel mechanic's helpers	.775
Glaziers	1.25
Iron workers, structural	1.625
Iron workers, ornamental	1.625
Iron workers, reinforcing	1.50
Iron workers, apprentices	
2/5 of journeymen's rate	
Laborers, concrete	.65
Laborers, unskilled	..625
Lathers	1.50
Marble setters	1.50
Marble setter's helpers	.775

Type of Worker	Wage per Hour
Mason tenders	$ 0.65
Mortar mixers	.75
Painters, brush	1.25
Painters, sign	1.25
Painters, spray	1.50
Painters, structural steel	1.50
Painter's apprentices:	
1st year	.50
2nd year	.75
3rd year	1.00
Piledrivermen	1.25
Pipe layers (concrete and clay)	.75
Plasterers	1.50
Plasterer's tenders	.65
Plumbers	1.625
Plumber's helpers	.775
Power Equipment Operators:	
Air Compressors, portable	1.00
Air Compressors, stationary	1.25
Blaze graders	1.25
Bulldozers	1.375
Cranes, derricks, draglines	1.625
Hoists, 1 drum	1.00
Hoists, 2 or more drums	1.50
Mixers (less than 1 yd.)	1.00
Mixers (1 yd. and over)	1.25
Motor graders	1.25
Piledrivers	1.625
Pumps	1.00
Rollers, earth	1.00
Rollers, bituminous	1.25
Scrapers (pan-tournapull type)	1.50
Shovels	1.625
Tractors (under 50 h.p.)	1.00
Tractors (50 h.p. and over)	1.25
Trenching Machines	1.375
Roofers, composition	1.125
Roofers, slate and tile	1.125
Roofer's helpers	.625
Sheet Metal Workers	1.50
Sheet Metal Worker's apprentices:	
1st 6 months 35% of journeymen's rate	
2nd " " " " " "	
3rd " " " " " "	
4th " " " " " "	
5th " " " " " "	
6th " " " " " "	
7th " " " " " "	
8th " " " " " "	
Soft floor layers (linoleum)	1.25
Steam Fitters	1.625

Type of Worker	Wage per Hour
Steam fitter's helpers	$ 0.775
Sprinkler fitters	1.58
Sprinkler fitter's helpers	.95
Stone masons	1.625
Terrazzo workers	1.50
Terrazzo worker's helpers	.775
Tile setters	1.50
Tile setter's helpers	.775
Truck drivers:	
Under 3½ tons (including dump trucks under 3 cu. yds.)	.70
3½ to 7½ tons (including dump trucks 3 to 6 cu. yds.)	.85
7½ tons and over (including dump trucks over 6 cu. yds.)	1.00
Special equipment (winch truck, refrigerator truck, trailer truck, etc.)	1.00
Fuel delivery	.85
Power system construction (special equipment)	1.00
Water proofers	1.125
Welders- receive rate prescribed for craft performing operation to which welding is incidental	
Well-drillers	1.125
Well-driller's helpers	.75
Wreckers	1.25

MANHATTAN DISTRICT HISTORY

BOOK VI - LIQUID THERMAL DIFFUSION (S-50) PROJECT

APPENDIX "F"

BIBLIOGRAPHY OF SCIENTIFIC PUBLICATIONS

No.	Title
1.	D. Enskog, Physik. Zeits. 12, pp. 56 and 533, (1911)
2.	S. Chapman, Roy. Soc. Proc. 93, pp. 1-20, (1916)
3.	S. Chapman and F. W. Dootson, Phil. Mag. 33, p. 248, (1917)
4.	K. Clusius and G. Dickel, Naturwissenschaften 26, p. 546, (1938)
5.	A. Bramley and A. K. Brewer, J. Chem. Phys. 7, p. 553, (1939)
6.	Ludwig, Wien. Akad. Ber. 20, p. 539, (1856)
7.	S. Chapman, Phil. Mag. 7, pp. 1-16, (1929)
8.	H. Korshing and K. Wirtz, Naturwissenschaften 27, p. 110, (1939)
9.	K. Clusius and G. Dickel, Naturwissenschaften 27, (1939)
10.	S. Chapman, Phil. Mag. 38, p. 182, (1919)
11.	H. Korshing and K. Wirtz, Naturwissenschaften 27, p. 367, (1939)

MANHATTAN DISTRICT HISTORY

BOOK VI - LIQUID THERMAL DIFFUSION (S-50) PROJECT

APPENDIX "G"

FILE REFERENCES

No.	Reference
	References in the Manhattan District Classified Files
1.	Progress Report on Liquid Thermal Diffusion Process by P. H. Abelson, 4 January 1943, Par. 9 - M-1330
2.	op. cit. 1, Par. 10
3.	ibid.
4.	ibid.
5.	ibid.
6.	ibid.
7.	ibid.
8.	op. cit. 1, Par. 65
9.	op. cit. 1, Par. 11
10.	op. cit. 1, Par. 12
11.	op. cit. 1, Par. 13
12.	op. cit. 1, Par. 16
13.	op. cit. 1, Par. 14
14.	Letter from H. K. Ferguson Co. to Mehring and Hanson Company, 5 July 1944 - W-7409-eng-23
15.	"Visit to Dr. Abelson on 20 January 1943 at Naval Research Laboratory, Bellevue, D. C." - A-518
16.	Letter to P. C. Keith from K. Cohen on Thermal Diffusion Plant, 17 March 1943 - M-1339

No.	Reference
17.	Letter from K. P. Cohen and W. I. Thompson to W. K. Lewis regarding Isotope Separation Methods, 3 September 1943 - M-1341
18.	Memorandum from H. C. Urey on Liquid Thermal Diffusion Reports O-1977 and O-1981 (NRL), 22 January 1943
19.	op. cit. 1, Par. 50-57
20.	Second Partial Report on Liquid Thermal Diffusion by P. H. Abelson, 7 January 1943, Par. 15 - M-1331
21.	Production Rate vs. Assay Studies on Whole Circuits, Dwyer and Dodge, 25 April 1945 - M-2354
22.	Outline of Report of Accident Involving Use of C-616 - M-1201
23.	Manual of Operations for S-50 Plant, June 1945, p. C-15 - Man S 319.1
24.	op. cit. 23, p. B-4, C-4, H-1
25.	Fercleve Corporation Technical Division Final Report, Vol. I, 25 September 1945, Projects 2 and 12 - Man S 319.1
26.	Fercleve Corporation Technical Division Final Report, Vol. II, 25 September 1945, Project 40 - Man S 319.1
27.	Letter from C. W. Roberts to District Engineer, First Endorsement "Steam S-50", 16 February 1945 - MD-675
28.	Letter from Lt. Col. W. H. Bedell to Capt. Geiger, 10 October 1944, SPGCC MD-248 (Fercleve)
29.	Monthly Operations Report for S-50, March 1945 - Man S 600.914
30.	Monthly Operations Report for S-50, May 1945 - Man S 600.914
31.	Monthly Operations Report for S-50, April 1945 - Man S 600.914
32.	Fercleve Corporation Technical Division Final Report, Vols. I and II, 25 September 1945 - Man S 319.1
33.	Production Data Book - Man S 319.1

No.

Reference

34. Letter from Col. K. D. Nichols to Major T. J. Evans, Jr. on Re-routing S-50 Product, 28 April 1945 - MD-400.22

35. Standby Report for S-50 Area, September 1945 - Man S 600.914

36. Gamma Ray Survey by R. L. Macklin, 8 January 1945 - Man S 319.1

37. Memorandum to Col. K. D. Nichols from Capt. M. J. Barnett concerning S-50 Operating Costs, 16 May 1945 - Man S 121.6

References in the Manhattan District Production Control Division Files

38. P. C. Studies - Nos. 9, 13, 14, 19, 25, 30

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39. Wage and Salary Schedule - Man S 248.3 (Ferdeve)

MANHATTAN DISTRICT HISTORY

BOOK VI - LIQUID THERMAL DIFFUSION (S-50) PROJECT

APPENDIX "H"

GLOSSARY OF TECHNICAL TERMS

Term	Definition
1. Alpha counter	- an instrument designed to measure the intensity of the emission of alpha particles (positively charged sub-atomic particles) which are emitted from the uranium nucleus in the process of radioactive disintegration.
2. Annular space	- as used at S-50, this term applied only to the volume within the column which contained the process material. It was bounded on the outside by the concave surface of the copper tubing, and on the inside by the convex surface of the nickel steam pipe.
3. Critical pressure	- vapor pressure exerted by a substance at its critical temperature.
4. Critical temperature	- temperature above which a fluid cannot exist as a liquid, no matter how high the pressure is increased.
5. Duct	- compartment in the transfer room and at top and bottom of racks, heated by 150 p.s.i. steam, and enclosing such fittings as intercolumn connectors, link lines, freeze-off coils, and column tits, which must be maintained at a temperature above the freezing point of the process material.
6. Fission	- a breaking up into parts. The discovery of fission of the atom of Uranium-235, and its accompanying release of tremendous amounts of energy, was the beginning of the development of atomic energy.
7. Fluorination	- process of treating by exposure to the gas fluorine. It was used to remove the last traces of moisture and to form a protective fluoride film on nickel and copper surfaces. (For security purposes, fluorine was called "fresh air" at S-50.)

Term	Definition
8. Freeze-off coil	- a length of nickel tubing coiled and contained within either a 3/8 inch copper tube or an iron pipe.
9. Mass spectrometer	- instrument in which ions traveling at high speed are subjected to a strong magnetic field, the attraction of which causes the path of the particle to curve. Curvature occurs in inverse proportion to the mass of the individual atoms. Thus a separation of isotopes is effected, and the instrument can be used to measure the relative amounts of isotopes of a substance.
10. Radioactive disintegration	- process by which elements of high atomic number, such as uranium, thorium, and protoactinium, emit alpha, beta, and gamma rays, to become elements of different atomic number and mass. This process results when the nucleus of an element is unstable, and will continue through a whole series of disintegrations until an element with a stable nucleus is reached.
11. Relaxation Time	- time required for equilibrium conditions to be essentially reached within the columns, after which time the diffusional separation comes to a standstill.
12. Separation factor	- ratio of relative concentration of desired isotope after processing to its relative concentration before processing. The separation factor of an S-50 column can be defined as relative concentration of Uranium-235 at top of column divided by relative concentration at bottom of the column.
13. Soret effect	- (Ludwig phenomenon) an inequality of concentration which developes in different parts of a solution, initially homogeneous, when these parts assume different temperatures.

INDEX

(Abbreviations ..... App. = Appendix
NRL = Naval Research Laboratory)

- Abelson, P. H., 5.21, App. D1
  - Association of, with NRL, 2.4, 6.1
  - Employment of, by Carnegie Institution, 2.4
  - Interest of, in liquid thermal diffusion, 2.4
  - Position held by, in Fercleve Corporation, App. A4
  - Steam change endorsement by, App. D4
  - Work of, at Philadelphia Pilot Plant, 2.4
- Administration Building, App. E1
- Agnor, G. L., Capt., C.E., 6.2
- Alpha
  - Counter, 4.6, 5.17, App. H
  - Particles, 5.17
- Anacostia Naval Station, 2.4
  - Boiler installation at, 2.6-2.7
  - Completion of, 2.9
  - Tests at, 2.9
- Analysis, isotope, 2.6
- Annular space, 2.5, 2.8, 2.12, 3.4
  - Definition, App. H
  - Description, 4.2
  - Tolerance, 3.7
- Armor-plate barricade, 3.9, 4.4, 5.23
- Asbestos Magnesia Company, App. C17
- Assay Laboratories, 4.6, 5.16-5.17
  - Accuracy, 5.16-5.17
  - Buildings, App. E1
  - Equipment, 4.6
  - Personnel, 5.21-5.22
  - Samples, 5.14-5.17
- Atomic power, 2.4
- Atomic weights, isotopic, 2.3-2.4
- Authorization, 1.1-1.2
  - Hours, 5.22
  - New Boiler Plant construction, 3.19
  - Product specifications, 5.2
  - Project, 1.1
  - Rerouting of product, 5.15
  - Wages, 5.22
- Babcock and Wilcox Company, 3.12, 4.7, App. C18
- Bailey Meter Company, 4.7, App. C20
- Barricade, armor-plate, 3.9, 4.4, 5.23
- Boiler(s), 4.7 (See also "New Boiler Plant")
  - Control, 4.9
  - Feed pumps, 3.13, 4.7
  - House equipment, 4.7-4.10
  - Make-up pumps, 4.7
  - Plant No. 2, 3.14, 4.10, App. E1
  - Transportation, 3.19
- Bowen, Rear Adm., 6.1
- Bramley, 2.3
- Brewer, 2.3
- Buildings
  - Description of, 4.1-4.2, App. E1
  - Disposal of 5.28
- Bureau of Ships, 6.1
- Bureau of Standards, National
  - Analytical work by, 3.8
  - Abelson's experiments at, 2.4
- Buttons, 3.7
- Cafeteria, 4.1, 5.25, App. E1
- Calumet-Hecla Copper Company, App. C21
- Canteen, App. E1
- Capsule, 2.13, 4.5, 5.9, 5.14
- Carbide & Carbon Chemicals Corporation, App. C41
  - Objections to site selection, 3.5

Personnel from, 5.21-5.22
Carbon Tetrachloride, experiment with, 2.7
Carnegie Institution, 2.4
Change House, 5.25, App. E1
Chapman, S., 2.2, 2.3
Chapman Valve Manufacturing Company, App. C22
Chlorine isotope separation, 2.7
Clusius, 2.2, 2.3, 2.12
Circuit, 4.3, 5.6
Circulation, 5.6, 5.10
Coal, wet, 5.19
Cochran Company, App. C23
Column(s), 4.2-4.3, 5.18
Connecting of, 2.9, 2.13
Description, 4.2-4.3
Design, 3.4
Development, 2.4-2.9
Dimensions, 3.7, 4.2
Invention, 2.2-2.3
Materials of construction, 3.7, 3.8
Phenomena in, 2.1-2.2, 5.8
Use of, 4.2
Wall spacing of, 3.4, 4.2
Completion schedule, 3.15-3.17, App. D2
Condensate, 2.14
Difficulties concerning, 3.11, 5.19
Return, 3.11
System, 4.8
Condensers, description of, 4.8
Conditioning, 2.13, 5.17-5.18
Conditioning Shop, 5.18
Conduit, 4.3, 5.5
Consolidated Chimney Company, App. C16
Consolidated Shipbuilding Company, 3.19
Construction, 3.1-3.22
Chronology of, 3.18-3.20
Contractors,
List of, App. C1-17
Organizations of, 6.3
Contracts, 3.1-3.4, App. C1-17
Modifications of, 3.3-3.4, 4.12
New Boiler Plant, 3.2-3.4
Original construction, 3.1-3.2
Cost of, 3.22, App. D6
Ferguson, H. K. Company contract for, 3.1-3.2, 3.3, App. C1
Schedules, 3.15-3.17
Main Process Plant, 3.15-3.16
New Boiler Plant, 3.16-3.17
Contract(s), App. C
Construction, 3.1-3.4, App. C1-17
Modifications of, 3.3-3.4, 4.12
New Boiler Plant, 3.2-3.4
Original construction 3.1-3.2
Prime, 3.1, 3.3
Subcontracts, 3.2, 3.4, App. C6-17
Design, 3.1-3.2, 3.3
Fercleve Corporation, 5.1-5.2, App. C42
Ferguson, H. K. Company, 3.1-3.2, 3.3, App. C1
Operations, 5.1-5.2, App. C42
Contracting Officer, 6.2
Contractor(s), App. C
Construction, list of, App. C1-17
Design, 3.1-3.2, 3.3
Operations, 6.3, App. C41-42
Organizations, 6.3, App. A4, A5
Personnel, 6.3
Selection of
Operations, 5.1
Original construction, 3.1
New Boiler Plant construction, 3.2
Control
Process, 5.16
Product, 5.15
Rooms, 3.9, 4.1, 4.5
Cooling and Heating, Inc., App. C12
Cooling Water, 2.14
Equipment, 4.10
System, 3.14-3.15, 4.10
Description of, 4.10
Design of, 3.14-3.15
Purpose of, 2.14
Convection, 2.1
In column, 2.1
Loop, 2.13, 3.9, 4.4, 5.5
Costs, 1.2
Construction, 3.22, App. D6
Design, 1.2, App. B6
Operations, 1.2, 5.28-5.29, App. D5

Critical pressure, 2.13, App. H
Critical temperature, 2.6, 2.12-2.13, App. H
Curtiss, L. F., 2.6

Date(s)
Construction, 3.15-3.17, 3.18-3.20
Schedules, 3.15-3.17, App. A8
Discovery of phenomenon, 2.2-2.3
Operations, 5.2-5.5
Preliminary, 3.16, 3.18, 5.3-5.4
Termination of, 5.26-5.27, App. D7
Davidson, J. E., 6.3
Depleted material, 2.11, 2.13
Disposal, 5.13-5.14
Handling, 5.13-5.14
Description of plant, 4.1-4.13
Description of process, 2.11-2.14, 5.5-5.19
Design
Changes in, 3.12-3.13, 3.15, 5.20
Contracts, 3.1-3.2, 3.3
Cooling water system, 3.14-3.15
Costs, 1.2
Narrative, 3.4, 3.6
Process equipment, 3.6-3.9
Steam system, 3.9-3.14
Desuperheater pumps, 3.10, 4.6
Desuperheating nozzles, 3.10-3.11
Detroit, consideration for site, 3.5
Development
Operating process, 2.4-2.11
Preliminary, 2.4-2.5
Dickel, 2.2, 2.3, 2.12
Diffusion, 2.2
Dimensions, optimum, 2.7-2.8, 3.4, 4.2
Disposal
Buildings, 5.28
Equipment, 5.28
Records, 5.28
District Intelligence Office(r), 3.21, 5.25
Dodge, B. F., 6.3
Dole method, 5.10-5.11
Dootson, 2.2
Duct, 4.3, 4.6, App. H

Economizers, 3.12-3.13
Edenfield Electric Company, 3.20, App. C6
Electric power supply, 4.11-4.13
Elimination of plugs, 5.6-5.7
Employees
Complaints of, 5.22
Numbers of, 6.3, App. A9-10
Promotions of, 5.22
Reclassification of, 5.22
Recruiting of, 3.20-3.21, 5.21-5.22
Types of, App. A9-10, E2
Enriched Mixture, 2.11
Removal of, 2.13-2.14
Enskog, 2.2
Equilibrium separation, 2.8
Equipment
Conditioning, 5.17-5.18
Cooling water system, 3.14-3.15, 4.10
Disposal of, 5.28
Laboratories, 4.6
Process, 3.6-3.9, 4.2-4.6
Procurement of, 3.17-3.18
Steam system, 3.9-3.14, 4.6-4.10
Utilities, 4.11-4.13
Evans, Major Thos. J., Jr., 6.2
Duties of, 6.2, App. A3
Position held by, 6.2
Shutdown memo to, App. D7
Expansion joints, elimination of, 3.15
Experiments
Carnegie Institution, 2.4
High temperature, 2.6-2.7
National Bureau of Standards, 2.4-2.5
Explosion(s)
Obviation of dangers of, 3.9
Pilot Plant, 5.3
Uranium, 2.11

Feed and withdrawal system
Description, 4.5-4.6
Design, 3.8-3.9
Operation, 5.9-5.12, 5.14-5.15

Purpose, 2.13-2.14
- Fercleve Corporation, App. C42
Contract, 5.1-5.2
Development of operating process, 2.10
Expenditures, 5.28-5.29, App. D5
Fee, 5.2, App. D5
Formation of, 5.1
Organization, 6.3, App. A4
Personnel, 6.3
Safety engineers, 5.22-5.24
Schooling, 5.22
Technical Division, 2.10, 5.2, 5.15, 5.16
- Ferguson, Ethel Hancock, 6.3
- Ferguson, H. K. Company, 6.3, App. C1
Contracts, 3.1-3.2, 3.3
Design, 3.6, 3.9, 3.12, 3.19
Expenditures, App. C1
Labor Procurement, 3.20-3.21
Organization, 6.3, App. A5
Personnel, 6.3
Scope of Work by, 3.1-32, 3.3
Security Agent, 3.21
Selection of, 3.1, 3.2
Filling station, App. E1
First Aid Building, App. E1
Fission, 2.4, App. H
Fluorination, 5.18, App. H
Forced draft fans, 4.7-4.8
- Fox, M. C., Lt. Col., 6.2
Duties of, 6.2, App. A3
Letter of, on Washington Meeting, App. D1
Position held by, 6.2
Schedule memo to, App. D2
Freeze-off technique, 2.12, 4.3, 4.5-4.6, 5.6
Freeze-off water, 4.3, 4.10-4.11, 5.19
Fuel system, 4.6

Gaseous Thermal Diffusion, 2.2-2.3, 2.10
Gasoline Filling Station, App. E1
Gas supply, propane, 5.19
- General Electric Company, 5.17
- Gerow, C. H., Jr., Lt., U.S.N.R., 6.2
- Goodrich, B. F. Company, 3.15, App. C24
- Grinnell Company, Inc., 3.4, 3.7, 3.18, 3.20, App. C5,C25
- Griscom-Russell Company, 4.8, App. C26
- Groves, L. R., Maj. Gen., App. D1-2
Authorization by, 1.7
Selection of contractor by, 3.1

- Harshaw Chemical Company, 5.11
Heat to buildings, 4.11
High-pressure piping, 4.6-4.7, 4.9
Hoffman flowmeter, 4.3, 4.5
- Houghton Elevator Company, App. C15
Hours, 5.21, 5.22
Housing, 5.24-5.25
Hydrogen isotope separation, 2.3

Industrial Relations, 5.21-5.25
- Ingalls Iron Works, App. C27
Injury rates, 3.22, App. D8
Intelligence Office(r), 3.21, 5.25-5.26
Intercolumn circulation (See intercolumn mixing)
Intercolumn connector, 4.3, 5.6
Intercolumn mixing, 5.7-5.8
- International Nickel Company, App. C28
Isotope(s), 2.3
Chlorine, 2.7
Definition of, 2.3
Hydrogen, 2.3
Radioactive transformations of, 2.3, 2.11
Separation, 2.3-2.4
Uranium, 2.4, 2.11
Zinc, 2.3

- Jones, J. A. Construction Co., App. C2
Contract, 3.3, App. C2
Organization, 6.3
Scope of work, 3.19-3.20

K-25 Dispensary, 5.22-5.23
K-25 Guard Forces, 5.26-5.28
K-25 Power House, 3.2, 3.5, 3.9-3.11

- Kellex Corporation, 3.19, App. C19
- Kewanee Boiler Corporation, 4.10, App. C29
- King, Admiral Ernest J., 3.6
Korshing, 2.3

Laboratories, 4.6, 5.16-5.17
Accuracy, 5.16-5.17
Buildings, App. E1
Equipment, 4.6
Personnel, 5.21-5.22
Samples, 5.14-5.17
Labor procurement
Construction, 3.20-3.21
Operations, 5.21-5.22
- Lamie, R. S., 6.3
Liquid Thermal Diffusion, 2.1, 2.3
Losses of material, 5.13
Ludwig, 2.3
Lunkenheimer, 4.3

Machine Shop, App. E1
Main Process Building
Description of, 4.1, App. A6, B5-7
Design and construction of, 3.8-3.9, 3.15-3.16, App. B1-5
Make-up pumps
Boiler, 4.7
Cooling water, 4.10
Manhattan District, 6.1
Enlisted personnel, 6.2-6.3
Officer personnel, 6.2, App. A3
Mass spectrometer, 4.6, 5.16-5.17, App. H
Material (see "Uranium Hexafluoride")
Balance, 5.16
Circuit
Description, 4.2-4.4
Design, 3.8-3.9
Purpose, 2.13
Feed and withdrawal
Description, 4.5-4.6
Design, 3.9
Purpose, 2.13-2.14
Reservoir
Conditioning, 5.17-5.18
Description, 4.4
Design, 3.9
Purpose, 2.13
Material and Conditioning Shop, 5.18, App. E1
- Mehring and Hanson Company, 3.6-3.7, 3.8, 3.18, App. C30
Method of operation, 5.4-5.19
Mezzanine, 4.1
Milking, 2.13-2.14, 4.5-4.6, 5.6, 5.8, 5.9-5.10
Milker, 2.13-2.14, 4.5-4.6, 5.9-5.10
- Minnesota, University of, 5.17
Monorail, 4.5
Muscle Shoals, consideration of site at, 3.5

- National Bureau of Standards
Abelson's experiments at, 2.4
Analytical work by, 3.8
- National Valve and Manufacturing Company, App. C10
- Naval Office of Research and Invention, 6.1
- Naval Research Laboratory
Abelson's employment by 2.4
Contract with Carnegie Institution, 2.4
Design, 3.4, 3.6, 3.8-3.9, 3.10
Interest in thermal diffusion, 2.4
Objective, 1.2
Organization, 6.1
Pilot Plants (see Pilot Plants)
Process development, 1.2, 2.4-2.11
Review of progress of, 1.2
Steam specifications, 3.10
Change in, 3.12
Navy boilers, surplus, 3.19
New Boiler Plant
Building, 4.1, App. B7, B9, E1
Construction, 3.19-3.20
Contractors, 3.2-3.4
Personnel of, 6.3
Selection of, 3.2

Delivery system, 3.13
Design, 3.9-3.10, 3.12-3.14
Equipment, 4.7-4.10
Fuel Storage, 3.13-3.14, 4.9-4.10
Operation, 3.20
Piping, 4.9
Procurement, 3.17-3.18
Schedules, 3.15-3.17, App. A8
Steam specifications change, 3.12
-Nichols, K. D., Col., 6.2
Position held by, 6.2
Product specifications from, App. D3
Nickel tubes, 2.13
-Nier, Alfred O. C., 2.6
-Noland and Company, App. C31

Occupational injuries, 5.22-5.24, 5.25, App. D8
-Office of Scientific Research and Development, 1.2
Oil storage tanks, 4.9
Operations, 5.1-5.29
Contractor, App. C42
Selection of, 5.1
Contract summary, 5.1-5.2
Costs, 5.28-5.29, App. D5
Handicaps, 5.19-5.21
Hazards, 5.22-5.24
History, 3.18, 5.2-5.5
Industrial relations, 5.21-5.25
Officer's dutuies, 5.11, 5.15
Output, 5.4-5.5, App. A7
Personnel, 6.3
Procurement of, 5.21-5.22
Training of 5.3, 5.22
Procedure, 5.5-5.19
Security, 5.25-5.26
Termination, 5.26-5.27, App. D7
Optimum dimensions, 2.7-2.8
Organization, 6.1-6.3, App. A3-5

-Pacific Pumps, Inc., 3.10, 4.7, 4.10, App. C32
Personnel, 6.1-6.3
Construction, 6.3
Enlisted, 6.2-6.3
Officer, 6.2
Operations, 6.3
Procurement of, 3.20-3.21, 5.21-5.22
Naval, 6.1-6.2
Trained, lack of, 5.20-5.21
-Philadelphia Navy Yard
Pilot Plant at, 2.4, 2.9
Pilot Plant
Anacostia, 2.4, 2.6, 2.9
Philadelphia, 2.4, 2.9
Design of, 3.2, 3.4, 3.6
Steam unions at, 5.20
Training at, 5.3
Process development at, 2,4-2.9, 2.10, 2.11
Piping
High-pressure, 4.6-4.7, 4.9
New Boiler Plant, 4.9
Pitching, 2.9, 5.8-5.9
-Pittsburgh Piping and Equipment Company, App. C9
-Pittsburgh Testing Laboratory, App. C14
Plant (See Main Process Plant, New Boiler Plant, Water Treatment Plant)
Plugs, 5.6-5.7, 5.12, 5.17
-Pope, William A. Company, 3.3, 3.20, App. C3
Potassium salts, 2.5
Power supply, 4.11-4.13
Preliminary operations, 5.3-5.4
Present Development, 2.10-2.11
Prevention of intercolumn mixing, 5.7-5.8
Prevention of pitching, 2.9, 5.8-5.9
Process
Building, 4.1
Cooling water, 2.14, 3.14-3.15, 4.10
Control, 5.14, 5.16
Description of, 2.11-2.14, 5.5-5.19
Development, 2.4-2.11
Equipment
Description of 4.2-4.6
Design of, 3.6-3.9
Feed and withdrawal, 2.13-2.14, 3.8-3.9, 4.5-4.6
Material (See Uranium hexafluoride, Working substance)
Selection, 1.2-
Steam, 2.14, 3.9-3.13, 4.6-4.10
Procurement
Materials and equipment, 3.17-3.18
Personnel, 3.20-3.21, 5.21-5.22
Product
Blending, 5.14
Control, 5.15-5.16
Handling, 5.14

Delivery system, 3.13
Design, 3.9-3.10, 3.12-3.14
Equipment, 4.7-4.10
Fuel Storage, 3.13-3.14, 4.9-4.10
Operation, 3.20
Piping, 4.9
Procurement, 3.17-3.18
Schedules, 3.15-3.17, App. A8
Steam specifications change, 3.12
Nichols, K. D., Col., 6.2
Position held by, 6.2
Product specifications from, App. D3
Nickel tubes, 2.13
Nier, Alfred O. C., 2.6
Noland and Company, App. C31

Occupational injuries, 5.22-5.24, 5.25, App. D8
Office of Scientific Research and Development, 1.2
Oil storage tanks, 4.9
Operations, 5.1-5.29
Contractor, App. C42
Selection of, 5.1
Contract summary, 5.1-5.2
Costs, 5.28-5.29, App. D5
Handicaps, 5.19-5.21
Hazards, 5.22-5.24
History, 3.18, 5.2-5.5
Industrial relations, 5.21-5.25
Officer's dutuies, 5.11, 5.15
Output, 5.4-5.5, App. A7
Personnel, 6.3
Procurement of, 5.21-5.22
Training of 5.3, 5.22
Procedure, 5.5-5.19
Security, 5.25-5.26
Termination, 5.26-5.27, App. D7
Optimum dimensions, 2.7-2.8
Organization, 6.1-6.3, App. A3-5

Pacific Pumps, Inc., 3.10, 4.7, 4.10, App. C32
Personnel, 6.1-6.3
Construction, 6.3
Enlisted, 6.2-6.3
Officer, 6.2
Operations, 6.3
Procurement of, 3.20-3.21, 5.21-5.22
Naval, 6.1-6.2
Trained, lack of, 5.20-5.21
Philadelphia Navy Yard
Pilot Plant at, 2.4, 2.9
Pilot Plant
Anacostia, 2.4, 2.6, 2.9
Philadelphia, 2.4, 2.9
Design of, 3.2, 3.4, 3.6
Steam unions at, 5.20
Training at, 5.3
Process development at, 2,4-2.9, 2.10, 2.11
Piping
High-pressure, 4.6-4.7, 4.9
New Boiler Plant, 4.9
Pitching, 2.9, 5.8-5.9
Pittsburgh Piping and Equipment Company, App. C9
Pittsburgh Testing Laboratory, App. C14
Plant (See Main Process Plant, New Boiler Plant, Water Treatment Plant)
Plugs, 5.6-5.7, 5.12, 5.17
Pope, William A. Company, 3.3, 3.20, App. C3
Potassium salts, 2.5
Power supply, 4.11-4.13
Preliminary operations, 5.3-5.4
Present Development, 2.10-2.11
Prevention of intercolumn mixing, 5.7-5.8
Prevention of pitching, 2.9, 5.8-5.9
Process
Building, 4.1
Cooling water, 2.14, 3.14-3.15, 4.10
Control, 5.14, 5.16
Description of, 2.11-2.14, 5.5-5.19
Development, 2.4-2.11
Equipment
Description of 4.2-4.6
Design of, 3.6-3.9
Feed and withdrawal, 2.13-2.14, 3.8-3.9, 4.5-4.6
Material (See Uranium hexafluoride, Working substance)
Selection, 1.2-
Steam, 2.14, 3.9-3.13, 4.6-4.10
Procurement
Materials and equipment, 3.17-3.18
Personnel, 3.20-3.21, 5.21-5.22
Product
Blending, 5.14
Control, 5.15-5.16
Handling, 5.14

Rerouting, 5.15
Specifications, 1.1, 5.2, App. D3
Utilization, 1.1
Production
Initial, 5.4
Large-scale, 5.4
Record, App. A7
Production Plant Development, 2.10
Project
Authorization for, 1.1-1.2
Costs of, 1.2
Groundwork for, 1.2, 2.2-2.11
Personnel connected with, 6.1-6.3
Purpose of, 1.1
Selection of, 1.2
Propane gas, 5.19
Pseudo-equilibrium time, 2.8
Pump houses, 4.1, App. E1
Purpose of project, 1.1

Rack
Description, 4.2-4.4
Design, 3.6, 3.8
Operation, 5.5
Radioactive disintegration, 2.11, App. H
Rail transportation, 4.13
Ration Board, 5.25
Raw material, 5.11-5.12
Records, disposal of 5.28
Recycling, 2.11-2.12
Relaxation time, 2.5, App. H
Rerouting of product, 5.15
Research and Development, 2.1-2.14
Naval Research Laboratory, 2.4-2.11
Reservoir, 2.13
Conditioning, 5.17-5.18
Description, 4.4
Design, 3.9
Operation, 5.11-5.12, 5.13
Revere Copper and Brass Company, App. C33
Roberts, C. W., 6.3
Robertson, H. H. Company, App. C8

Safety, App. D8
Construction, 3.21-3.22
Operations, 5.22-5.24
Salt solutions, use of, 2.3, 2.5
Salvage material, handling of, 5.12-5.13
Sampling and control equipment, 4.6, 5.14-5.17
Schedules, completion, 3.15-3.17, App. D2
Schooling, 5.22
Schulman, A. S. Electric Company, 3.19, App. C4
Scope of project, 1.1
Section, 3.11, 4.2-4.3
Security, 3.21, 5.25-5.26
Affecting selection of contractor, 3.1
Selection
New Boiler Plant construction contractors, 3.2
Operations contractor, 5.1
Original construction contractor, 3.1
Process, 1.2
Separation factor, 2.8, App. H
Separation, isotopic, 2.3-2.4, 2.8
Chlorine, 2.7
Hydrogen, 2.3
Uranium, 2.4
Zinc, 2.3
Sewage disposal, 4.11
Shutdown, 5.26-5.28, App. D7
Decision to, 5.26-5.27
Site
Clearing, 3.18, 3.19
Location, 3.5
Objections, 3.5
Ownership, 3.5
Selection, 3.5
Soret effect, 2.3, App. H
Special Engineer Detachment, 5.20-5.21, 6.2-6.3
Work at Philadelphia Pilot Plant, 5.3
Specifications
Product, 1.1, 5.2, App. D3
Steam, 3.10, 3.12, App. D4
Speed of construction, need for, 3.1, 3.15-3.17
Stack temperature, 3.12-3.13
Steam, 2.14, 3.9-3.14, 4.6-4.10
Delivery, 3.11, 3.13
Department, 5.19
Desuperheating, 3.10-3.11
Distribution, 5.19
Heat, 4.11

K-25 Power House, 3.9-3.12
Lack of, 3.9, 5.19
Leaks, 5.3-5.4, 5.19-5.20
Mixing of, 3.10
Venturi for, 3.10
New Boiler Plant, 3.12-3.14, 4.7-4.10
Process, 2.14
Purpose of, 2.14
Requirements of, 3.10-3.11, 3.12
Specifications, change in, 3.12
Supply, 3.9-3.10
System
Design of, 3.9-3.14
Equipment, 4.6-4.10
Storage chamber (See reservoir)
Storage Shed, App. E1
Storage tanks, oil, 4.9, App. B7-8
Struthers-Wells Corporation, 4.8, App. C34
Sturtevant, B.F. Company, 4.7, App. C35
Subcontractors, 3.2-3.4, App. C6-17
Subcontracts, 3.2, 3.4, 3.19, App. C6-17
Sulphur, weld failure caused by, 3.8
Superheater, 3.12, 4.7
Swartwout Company, App. C36
Switch House, App. E1

Tank Farm, 3.13-3.14, 4.9-4.10, App. B7-8
Capacity, 3.13, 4.9
Construction, 3.20
Design, 3.13-3.14
Equipment, 4.9-4.10
Technical Division, 2.10, 5.2, 5.15, 5.16
Technical Service Unit, 6.2-6.3
Temperature difference, 2.5, 2.12-2.13, 4.2
Tennessee Roofing Company, App. C11
Termination
Employees, 5.27-5.28
Operations, 5.26-5.27, App. D7
Theory, 2.1-2.2
Development of, 2.2-2.4
Explanation of, 2.1
History of, 2.2, 2.4
Thermal Diffusion
Definition of, 2.1-2.2
Demonstration of, 2.2-2.3
Discovery of, 2.2
Gaseous, 2.2-2.3, 2.10
Liquid, 2.1, 2.3
Thompson, W. N., 6.3
Throttling, 3.10-3.11, 4.6
Time Office and Clock Alley, App. E1
Tits, 3.8, 4.3, 5.6
Training of operations personnel, 5.3, 5.20-5.21, 5.22
Transfer pot, 5.11
Transfer rooms, 3.9, 4.1, 4.4, 5.11
Transportation, 4.13
Boilers, 3.19, 4.13
Personnel, 5.25
Rail, 4.13
Water, 4.13
Tri-States Asbestos Company, App. C13
Turner and Ross Construction Company, 3.20, App. C7

Unions, pipe, replacement of, 3.18, 5.19-5.20
Unit Chief, 6.2
United States Employment Service, 3.21, 5.21
University of Minnesota, 5.17
Uranium
Fission, 2.4
Hexafluoride
Analysis, 2.6
Corrosiveness, 2.6, 2.13, 3.8
Depleted, 2.11, 5.13-5.14
Enriched, 2.11, 5.14-5.15
Handling, 5.11-5.15
Large scale preparation, 2.6, 6.1
Losses, 5.13
Molecule, 2.12
Production, method of, 2.6
Properties of, 2.6, 2.11-2.13
Raw, 2.13, 5.11-5.12
Salvage, 5.12-5.13
Sampling, 5.13-5.17
Selection, 2.5-2.6
Unavailability, 2.6
Use as working substance, 1.1,

2.6, 2.12, 2.13
Isotopes, 2.4, 2.11
Separation of, 2.4
USED personnel, 5.21
Utilities
Description of, 4.11-4.13
Supplying of, 5.19

Valves
Material, 2.12, 2.13, 5.5
Throttling, 3.10, 4.6
Van Keuren, Rear Admiral, 6.1
Venturi type desuperheating elements, 4.6

Wages
Construction, 3.21, App. E2
Operations, 5.22
Wall spacing (See "Annular space")
War Manpower Commission, 3.20
War Wage Administration Agency, 5.22
Washington Liaison Office, 3.17, 3.20
Water
Cooling, 2.14, 3.14-3.15
Freeze-off, 4.3, 4.10-4.11, 5.19
Potable, 4.11
Supply of, 3.14-3.15, 3.19, 4.3, 4.11
Transportation by, 4.13
Use of, as working substance, 2.3 2.12
Water Treatment Plant, 4.1 4.11, App. E1
Watt's Bar, consideration of site at, 3.5
Welding failure, 3.8
Westinghouse Electric and Manufacturing Company, 4.7, 4.8, App. C37
Williams and Company, Inc., App. C38
Wirtz, 2.3
Withdrawal, product, 2.13-2.14, 3.9, 4.5-4.6, 5.6-5.8, 5.9-5.11
Working conditions, 5.25
Working substance (See also "Uranium Hexafluoride")
Carbon Tetrachloride used as, 2.7
Potassium salt solutions used as, 2.5
Water used as, 2.3, 2.12
Zinc salt solutions used as, 2.3
Worthington Pump and Machinery Company, 4.8, 4.10, App. C39

Youngstown Welding and Engineering Company, App. C40